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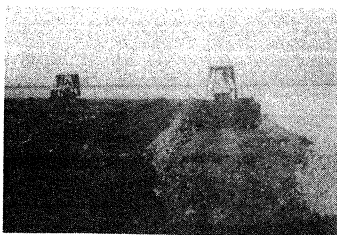
EVALUATION OF DREDGED MATERIAL FOR USE AS SANITARY LANDFILL COVER

by

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PREFACE

This report was prepared by the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES), as part of a reimbursable project for the US Army Engineer District, New York. Funding for this investigation was authorized by IAO NYD-84-69.

The report was prepared by Dr. Marian E. Poindexter under the general supervision of Dr. John J. Ingram, Chief, Water Resources Engineering Group (WREG), EL; Dr. Raymond L. Montgomery, Chief, Environmental Engineering Division (EED), EL; and Dr. John Harrison, Chief, EL. Acknowledgement is made to Mr. Daniel A. Leavell, Soils Research Facility, Geotechnical Laboratory, EL, for conducting the laboratory consolidation testing program. The assistance of Mrs. Cheryl M. Lloyd, WREG, is also acknowledged. Technical reviewers for this report were Drs. Michael R. Palermo, EED, and Gary F. Goforth, WREG.

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EVALUATION OF DREDGED MATERIAL
FOR USE AS SANITARY LANDFILL COVER

PART I: INTRODUCTION

Background

1. As a part of the Dredged Material Disposal Management Plan for the Port of New York and New Jersey, the US Army Engineer District, New York (NYD) has conducted numerous studies to identify and evaluate potential disposal alternatives for sediments dredged from the New York Harbor area. One of the potential uses of dewatered dredged material is as sanitary landfill cover. Initial feasibility studies (Malcolm Pirnie, Inc. 1982 and 1983) indicated that dewatered dredged material has properties which will allow it to be successfully utilized as daily, intermediate, and/or final landfill cover in some cases.

2. Use of dredged material as cover in sanitary landfills would have two beneficial effects in the NY/NJ Harbor area: (a) the availability of suitable cover material would be maintained; additionally, the cost of cover material would not escalate rapidly in future years as a result of scarcity of cover material, and (b) the service life of dredged material containment areas would be increased since material would be removed for landfill cover uses.

3. In order to use dredged material as cover, the dredged material must be dewatered or dried to a water content which is acceptable for use in a sanitary landfill. Research conducted at the US Army Engineer Waterways Experiment Station (WES) has indicated that evaporative drying is the most cost effective means of dewatering dredged material (Haliburton 1978). The effectiveness of evaporative drying is partially controlled by climatic conditions existing at the dredged material containment area as well as by the consolidation and permeability characteristics of the dredged material.

Purpose

4. The purpose of this study was to investigate the consolidation and dewatering characteristics of 10 sediment samples identified by the NYD. This

work included laboratory testing for material characterization, consolidation/desiccation (dewatering) analysis utilizing mathematical models, and comparison of results for the ten discrete sediment samples.

PART II: FIELD SITES

Sediment Samples

5. In previous studies, sediments from various locations within the New York Harbor area have been extensively sampled. By utilizing sediment classification and properties determined from the previous investigations, NYD personnel identified representative sediment samples to be tested in the present study. Ten sediment sampling sites were selected from the 23 harborwide sites initially investigated. The criteria used in selection of the 10 representative sediment sampling locations included:

- a. Geographical location within the harbor.
- b. Volume of material to be dredged.
- c. Grain size analysis.
- d. Atterburg limits.
- e. EP toxicity tests.

Eight of the sampling locations were selected based solely upon the above criteria; two additional locations (Lower Passaic and Lower Hackensack) were included since these projects may potentially be used for the thick lift study at De Korte State Park (Malcolm Pirnie, Inc. 1983). The ten sediments analyzed in this study are listed and identified by their various designations in Table 1.

6. Sediment samples were collected by NYD personnel at each of the ten sites previously identified. Since all of the sediments are part of future maintenance dredging projects (as opposed to new work dredging projects), grab sampling techniques were utilized. This technique is more expedient and more economical than is a subaqueous coring operation, and for maintenance dredged material it provides a suitable representative sediment sample.

7. Approximately five gallons of sediment were collected at each of the 10 sites during the period April-May 1984. The material from each site was sealed in a 5-gallon plastic bucket which was labeled with appropriate site identification codes. The ten buckets were subsequently shipped to the WES at the end of May 1984 for laboratory testing and analysis.

Table 1
Sediment Sampling Locations in the New York Harbor Area

<u>Sampling Site No.*</u>	<u>Corps Project No.</u>	<u>Project</u>
1. (1)	64D	Lower Hackensack
2. (3)	64E	Lower Passaic
3. (4)	64C	Port Elizabeth
4. (5)	64B	Newark Bay
5. (9)	Non-Federal	US Metals
6. (12)	63A	Seguine Point Bend
7. (13)	Non-Federal	Earle Navy
8. (17)	34	Red Hook Channel
9. (20)	39	Dutch Kills
10. (21)	Non-Federal	Port Authority NY/NJ Terminals

* Numbers in parentheses indicate sampling site numbers used by Malcolm Pirnie, Inc. (1982 and 1983).

Dewatering Disposal Sites

8. The NYD has conducted extensive investigations to locate regional upland disposal sites for containment and possible dewatering of dredged material. As a result of these investigations, six sites have been identified as potential dredged material dewatering sites. These sites are N37, N61, L13, N30, Raritan Center, and Newark Bay. Locations of these sites are shown in Figure 1 and sizes of the sites are listed in Table 2. Schematic drawings of the disposal sites are located in Appendix A.

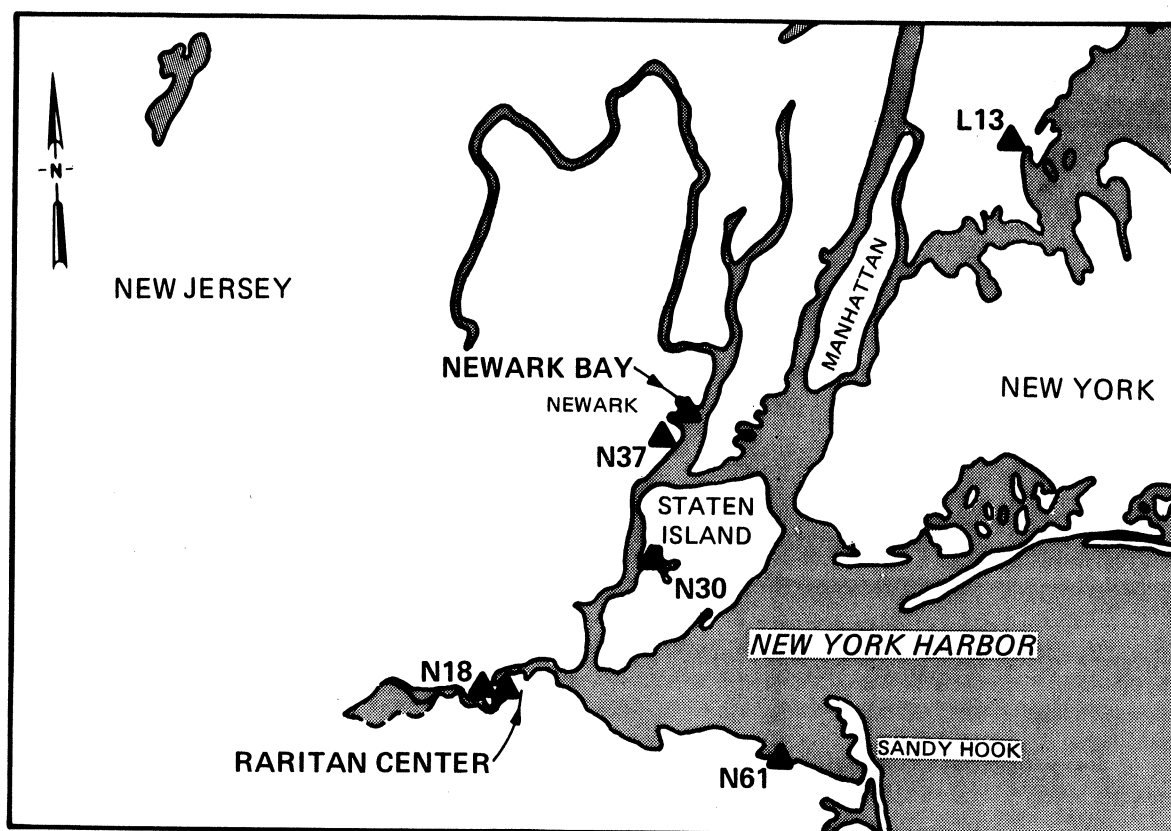


Figure 1. Locations of dewatering disposal sites in the New York Harbor area

Table 2
Size of Dewatering Disposal Sites
in the New York Harbor Area

<u>Site</u>	<u>Surface Area, acres</u>
N37	155
N61	82
L13	48
N30	64
Raritan Center	740
Newark Bay	165

PART III: LABORATORY INVESTIGATIONS

9. In order to predict the consolidation and dewatering behavior of dredged materials, laboratory testing to determine material properties must be accomplished. The properties which are of particular interest in this study are the void ratio-effective stress relationship and the void ratio-permeability relationship. These relationships are determined from various types of laboratory consolidation tests. The consolidation tests must be accompanied by soil classification tests which give indications of the basic differences in the sediment samples.

Soil Classification Tests

10. Upon receipt of the ten sediment samples from the NYD, each sample was classified by the WES Geotechnical Laboratory. The classification tests performed included Atterberg Limits, specific gravity, organic content, and grain-size distribution (both sieve and hydrometer analyses). Upon completion of these tests, each sediment was classified according to the Unified Soil Classification System (USCS) as described in US Army Engineer Waterways Experiment Station (1953). Table 3 shows the results of the soil classification tests for each of the sediment. Grain-size distribution curves for all sediments are included in Appendix B. It should be noted that the determination of the Atterburg Limits includes determination of both the liquid limit (LL) and the plastic limit (PL). The difference in these values is then calculated to obtain the value of plasticity index (PI). When a soil is non-plastic, the designation NP is given to the soil as was done in the case of the Lower Hackensack sediment.

11. Inspection of Table 3 indicates that the sediments tested exhibit a wide range of plasticity values, from a non-plastic sand to highly plastic clays (CH classification). The range of organic contents (0-12%) is typical of sediments to be dredged. The specific gravity values are consistently lower than would be expected for clays designated CH in the Unified Soil Classification System. Typically, sandy or silty clays have a specific gravity of about 2.72 and highly plastic clays have specific gravities in the range of 2.75 to 2.80. The lower specific gravities of the New York Harbor sediments may result from the presence of specific mineral grains which have lower

Table 3
Classification Test Results

<u>Sediment Location</u>	<u>Liquid Limits LL</u>	<u>Plasticity Index PI</u>	<u>Specific Gravity G_s</u>	<u>Organic Content %</u>	<u>USCS Classi- fication</u>
Lower Hackensack	NP	NP	2.60	0.8	SW-SM
Lower Passaic	101	63	2.50	12.0	CH
Port Elizabeth	84	49	2.57	8.5	CH
Newark Bay	41	19	2.64	3.0	SC
US Metals	115	71	2.54	12.6	CH
Seguine Point Bend	114	73	2.60	9.1	CH
Earle Navy	38	15	2.68	3.8	SC
Red Hook Channel	78	43	2.59	7.9	CH
Dutch Kills	90	50	2.42	12.3	OH
Port Authority NY/NJ	102	65	2.59	4.4	CH

individual specific gravities, or they may possibly result from the presence of contaminants in the sediments and interaction of these materials with the clay particles.

Consolidation Tests

12. A finite strain (large strain) consolidation testing program and theoretical analysis was utilized to analyze the New York Harbor sediment samples. This approach allows a more accurate prediction of field behavior of very soft materials (which may undergo 50 percent strain or more) than does the standard Terzaghi-Froehlich small strain consolidation theory.

13. Performance of a large strain consolidation testing program requires the conducting of two companion consolidation tests. A self-weight consolidation test is required to obtain soil properties at high void ratios (low densities). This test must be supplemented by another consolidation test in which the soil sample is subjected to an imposed vertical loading to simulate the loading conditions of the dredged material located deeper within the field deposit. The second test which is normally run is the large strain, controlled rate of strain (LSCRS) test; this test is conducted on a slurry of

fine-grained dredged material. Because of the classification of some sediment samples, i.e. more coarse-grained materials, the LSCRS test cannot be run on these sediments. In this case the self-weight consolidation test is supplemented by a standard consolidation test which is then analyzed by finite strain theory. Seven of the New York Harbor sediments were subjected to self-weight and LSCRS testing, two (Newark Bay and Earle Navy) underwent self-weight and standard consolidation tests, and one (Lower Hackensack) was not tested in consolidation since it is classified as a sand and was therefore not amenable to consolidation testing.

14. For any of the consolidation tests mentioned above, only fine-grained material (passing the No. 40 sieve) should be utilized. The slurry used in the self-weight and LSCRS testing should have a void ratio representative of the dredged material slurry as it enters the containment area or slightly higher. The water added to the sediment to obtain the appropriate void ratio should be from the dredging site, or water should be mixed to represent dredging site water, i.e., the pH and salinity should be representative of that at the project site.

Self-weight test

15. The self-weight consolidation device consists of a plexiglass cylinder which allows consolidation testing and subsequent incremental sampling of a specimen 6 in. in diameter and 9 in. high. Dredged material slurry placed in the consolidometer is allowed to undergo self-weight consolidation. Deformation versus time data are collected during the consolidation process. After completion of primary consolidation, the test device can be disassembled and the specimen sampled in 1/4-in. increments to obtain the necessary data to calculate void ratio, effective stress, and permeability values for the upper portion of the $e-\sigma$ and $e-k$ curves. Typical void ratios encountered in the specimen after completion of this test range from 5 to 12 (from bottom to top of specimen). This test should be performed as described by Cargill (1986).

Large strain test

16. The LSCRS test involved deformation of a large cylindrical specimen of slurry under a controlled, but variable, rate of strain. The specimen tested is 6 in. in diameter and 9 in. in height. During the test, measurements are made of the effective stress at each end of the specimen and the excess pore water pressure throughout the sample height. With these measurements, the required consolidation properties can be calculated for the lower

end of the range of void ratios encountered in a dredged material containment area. This test procedure is described by Cargill (1986).

Standard test

17. The standard consolidation test is run on a remolded soil specimen which is at a water content typical of the in situ channel sediment. The test specimen is 1.25 in. high and 4.25 in. in diameter. This test should be run in accordance with EM 1110-2-1906 (Office, Chief of Engineers 1970).

Consolidation Test Results

18. The void ratio-effective stress ($e-\sigma'$) and the void ratio-permeability ($e-k$) relationships for each sediment were developed from the laboratory test data in order to analyze the compressibility and dewatering characteristics of these materials. The curves were developed by combining results from the self-weight consolidation test and LSCRS test, except in the cases of the Newark Bay and Earle Navy sediments. For these two sediments, results from the self-weight and the standard consolidation tests were combined to form the required curves. The $e-\sigma'$ and $e-k$ relationships for each sediment are shown in Figures 2 through 19.

19. As shown on the $e-\sigma'$ and $e-k$ curves, the value of the initial void ratio e_o is that at which a particular laboratory test was begun. For instance, the self-weight consolidation test on the US Metals sediment was begun at an initial void ratio, e_o , of 14.0 and the LSCRS test was begun at $e_o = 11.09$. The higher initial void ratio was utilized in the self-weight test in order to be certain that this test was begun at a void ratio, e_o , which was higher than the zero-effective-stress void ratio e_{oo} . (The void ratio e_{oo} indicates the point at which the process of consolidation begins; therefore the test must begin at a higher void ratio if the entire $e-\sigma'$ and $e-k$ relationships are to be developed.) The zero-effective-stress void ratio is the void ratio at which the $e-\sigma'$ curve becomes approximately horizontal.

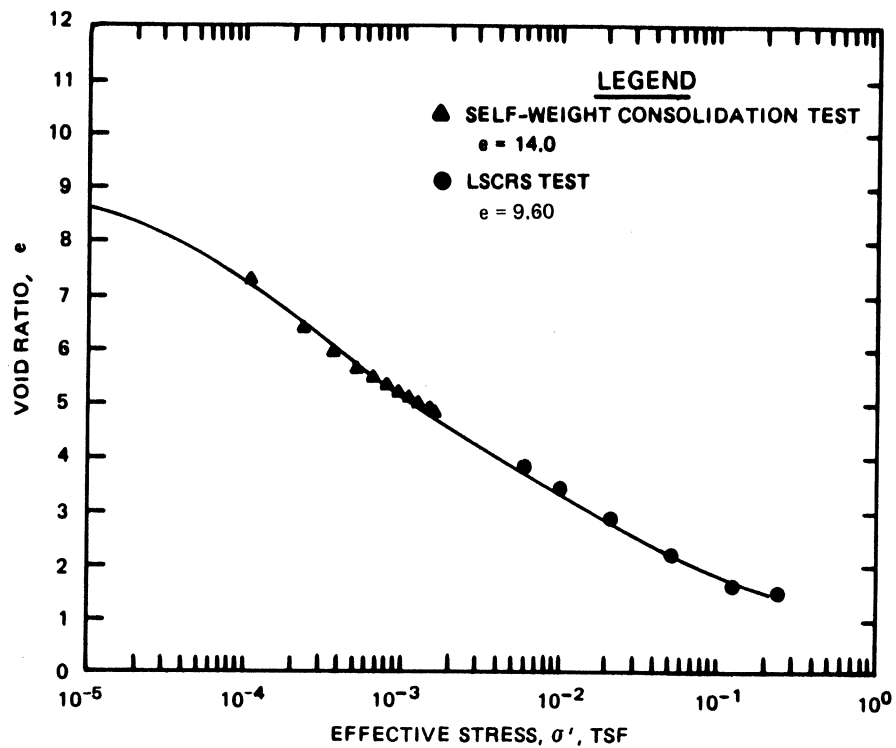


Figure 2. Void ratio-effective stress relationship, Lower Passaic

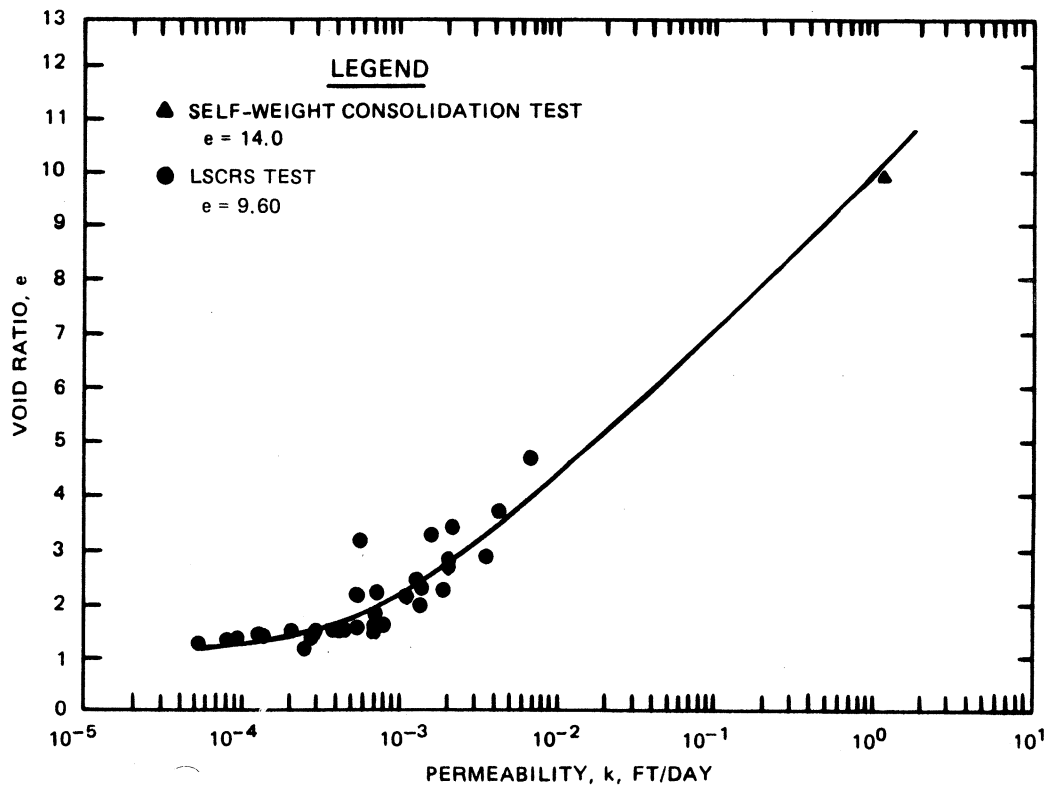


Figure 3. Void ratio-permeability relationship, Lower Passaic

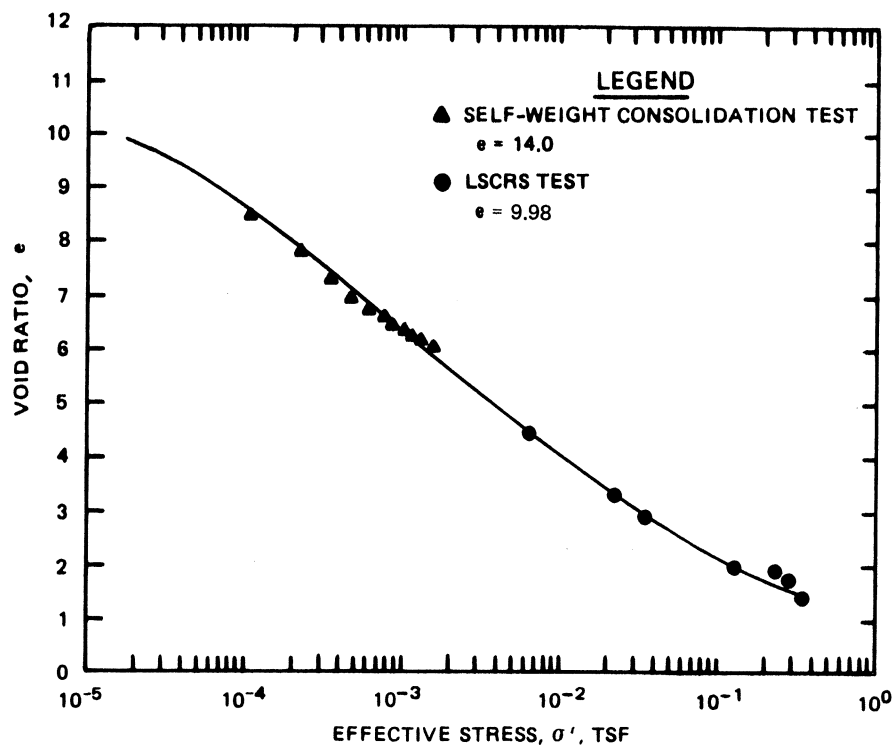


Figure 4. Void ratio-effective stress relationship, Port Elizabeth

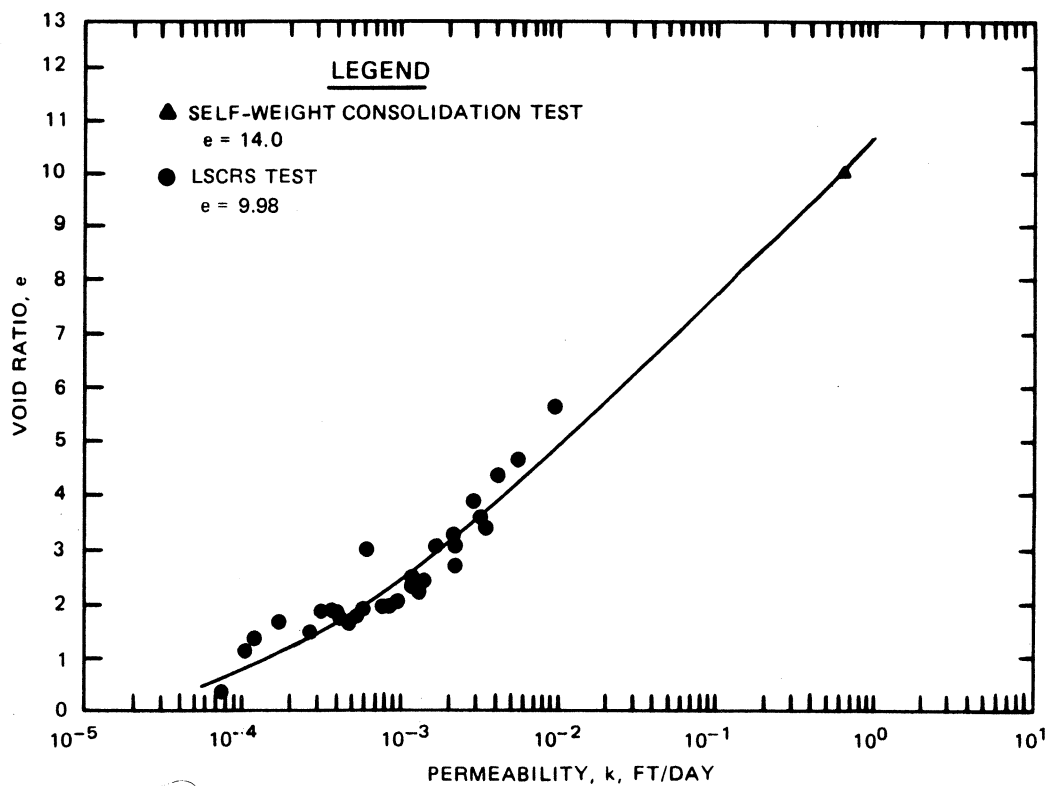


Figure 5. Void ratio-permeability relationship, Port Elizabeth

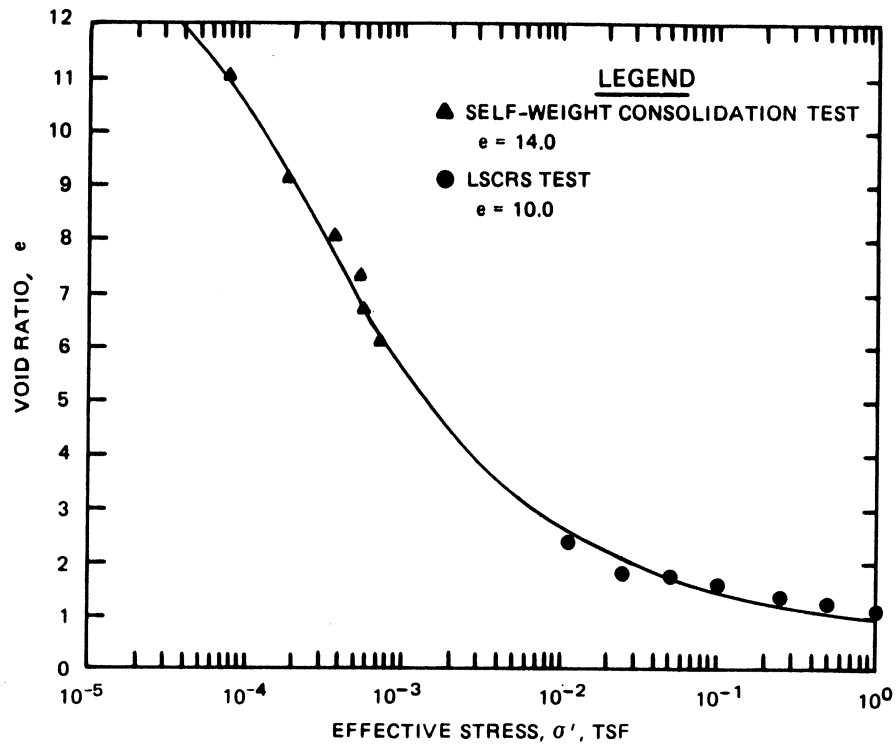


Figure 6. Void ratio-effective stress relationship, Newark Bay

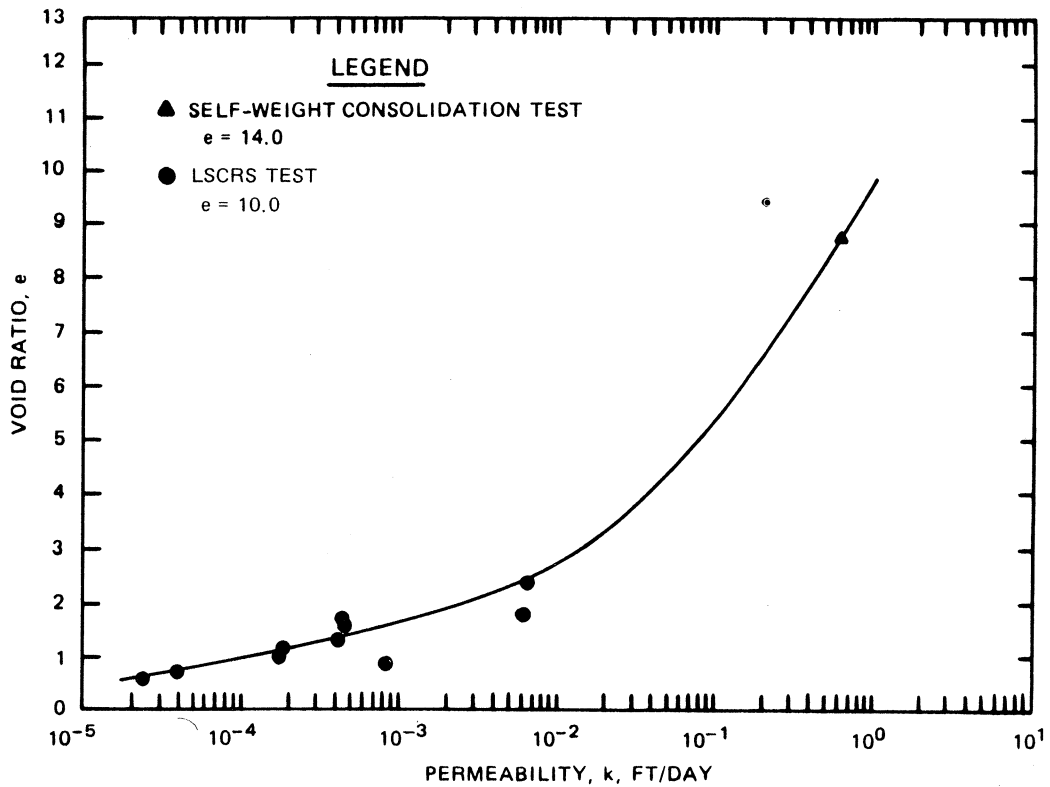


Figure 7. Void ratio-permeability relationship, Newark Bay

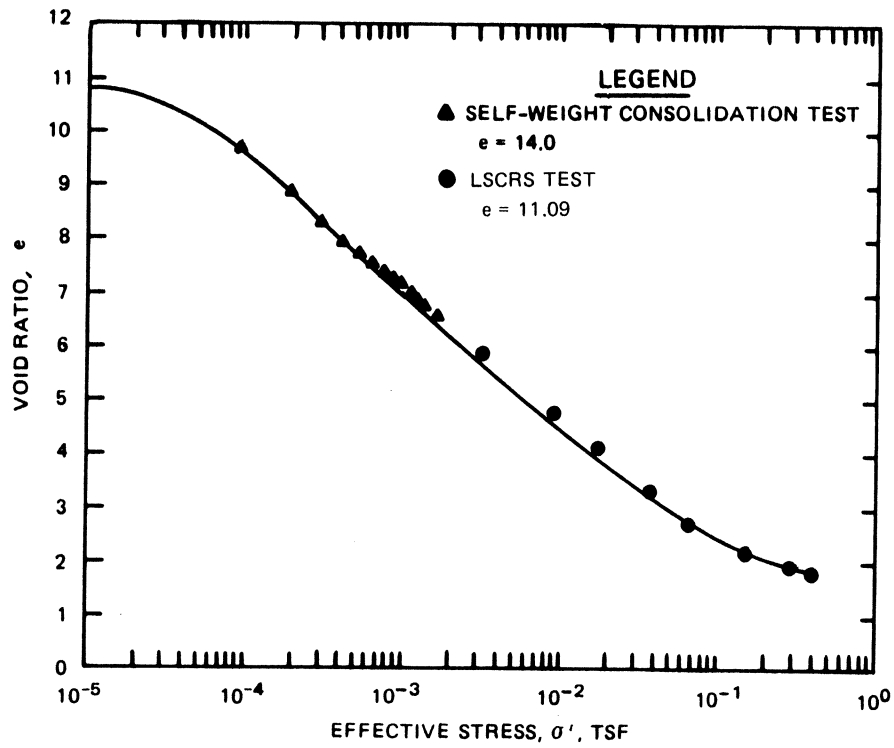


Figure 8. Void ratio-effective stress relationship, US Metals

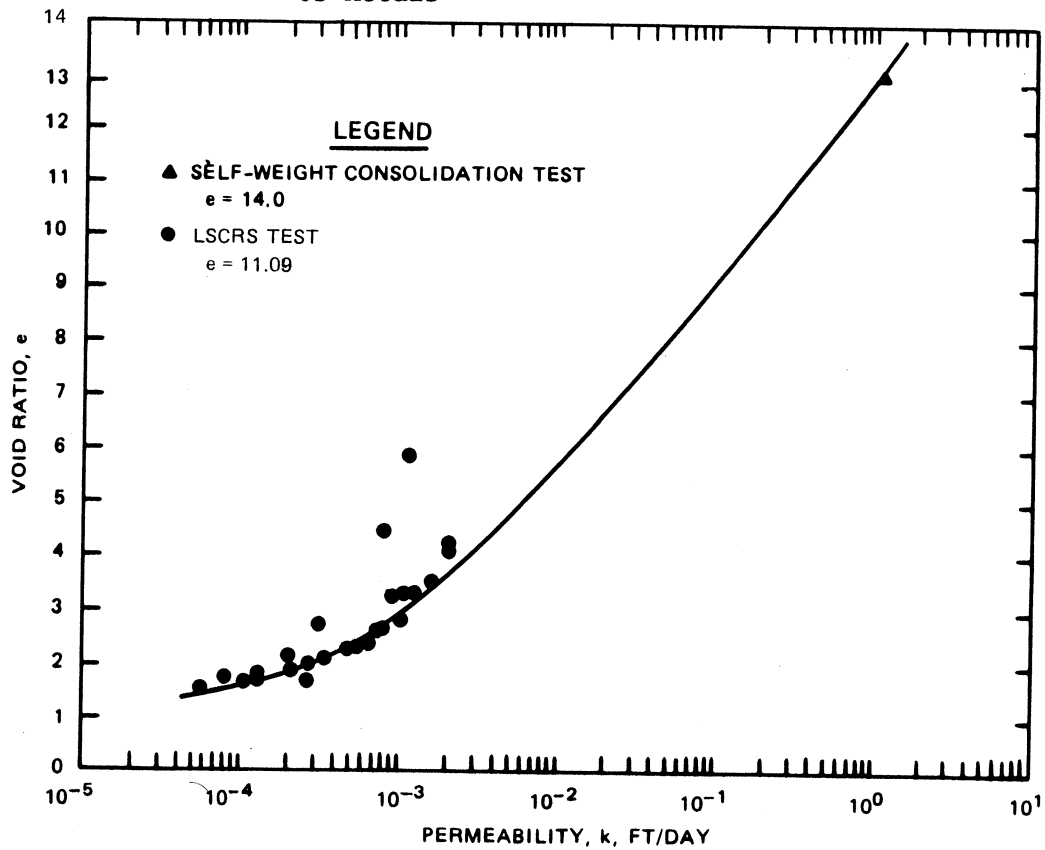


Figure 9. Void ratio-permeability relationship, US Metals

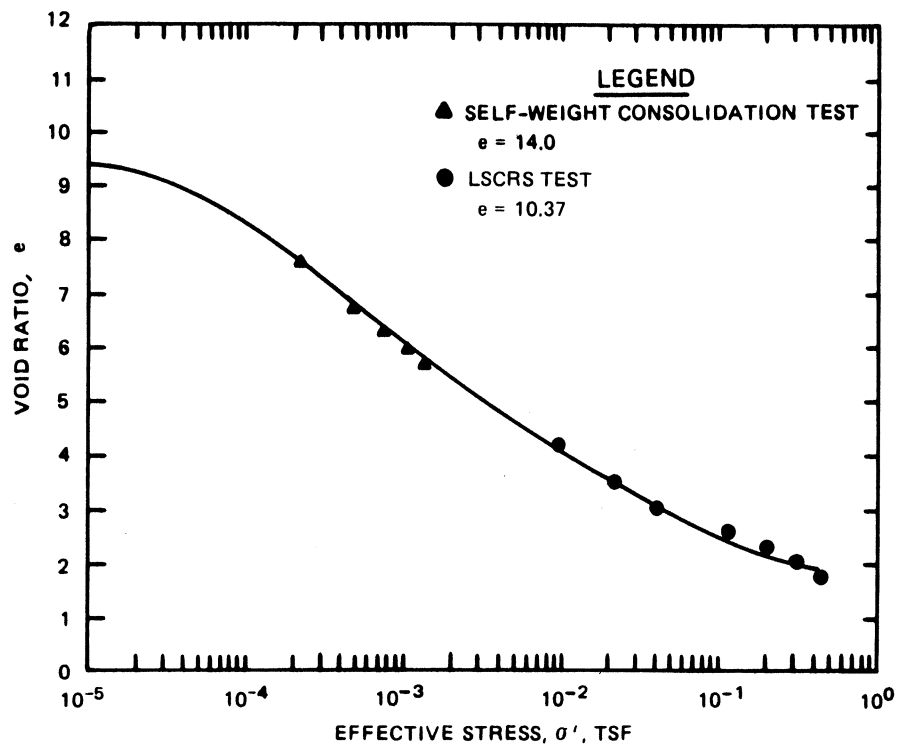


Figure 10. Void ratio-effective stress relationship, Seguiné Point

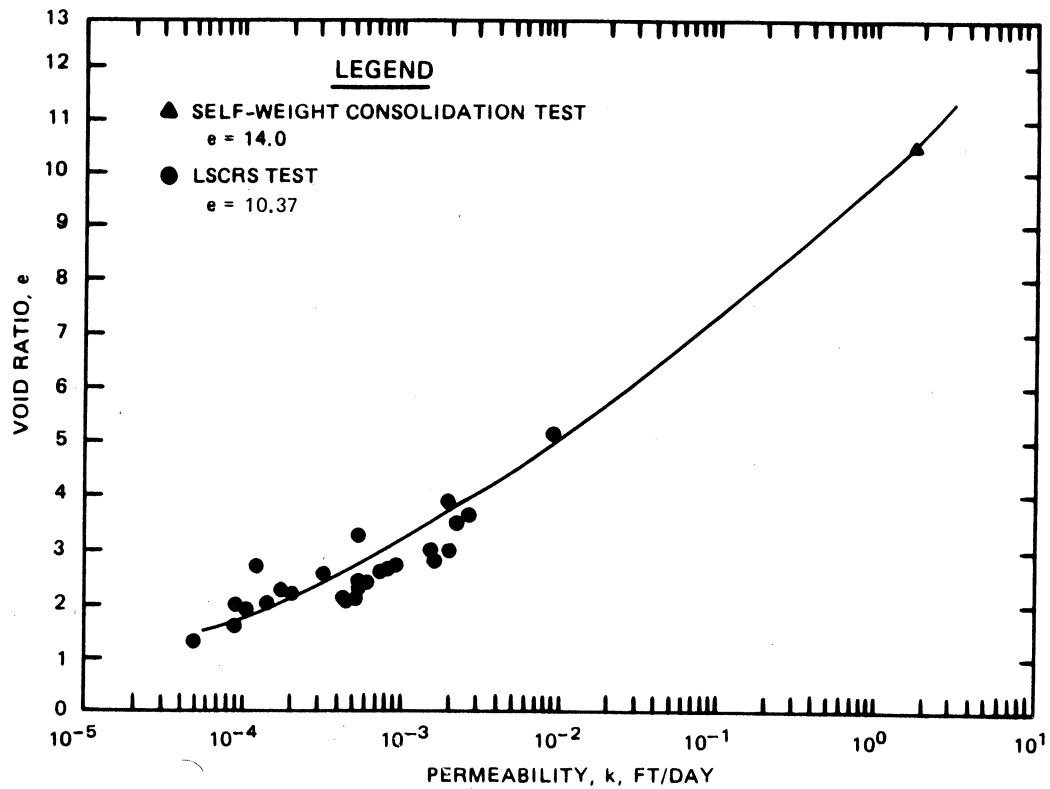
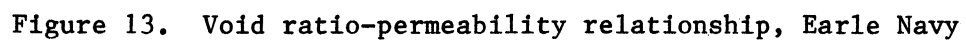
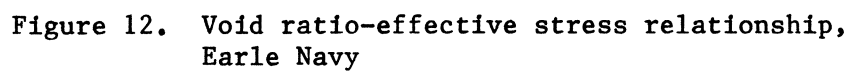


Figure 11. Void ratio-permeability relationship, Seguiné Point



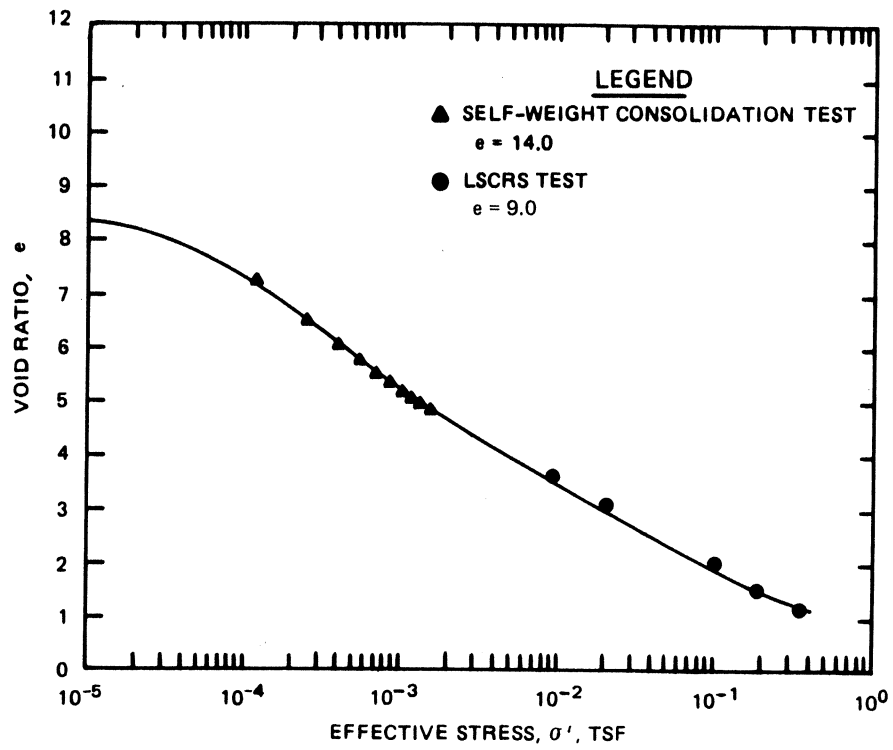


Figure 14. Void ratio-effective stress relationship, Red Hook

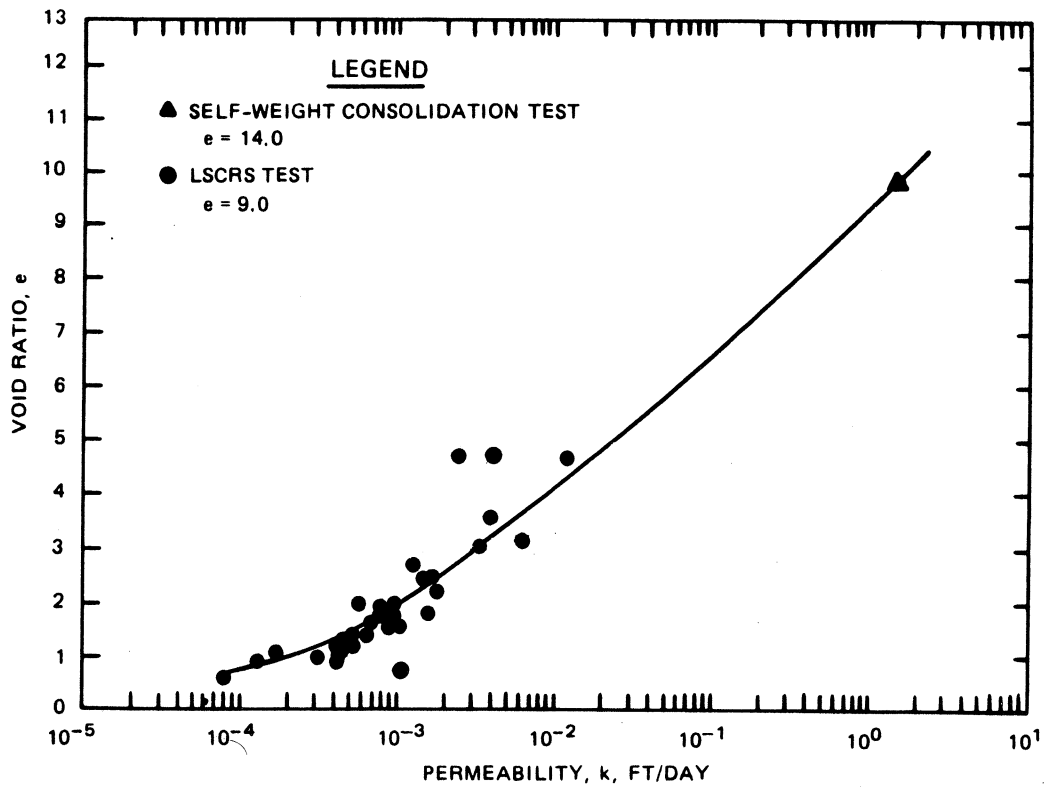


Figure 15. Void ratio-permeability relationship, Red Hook

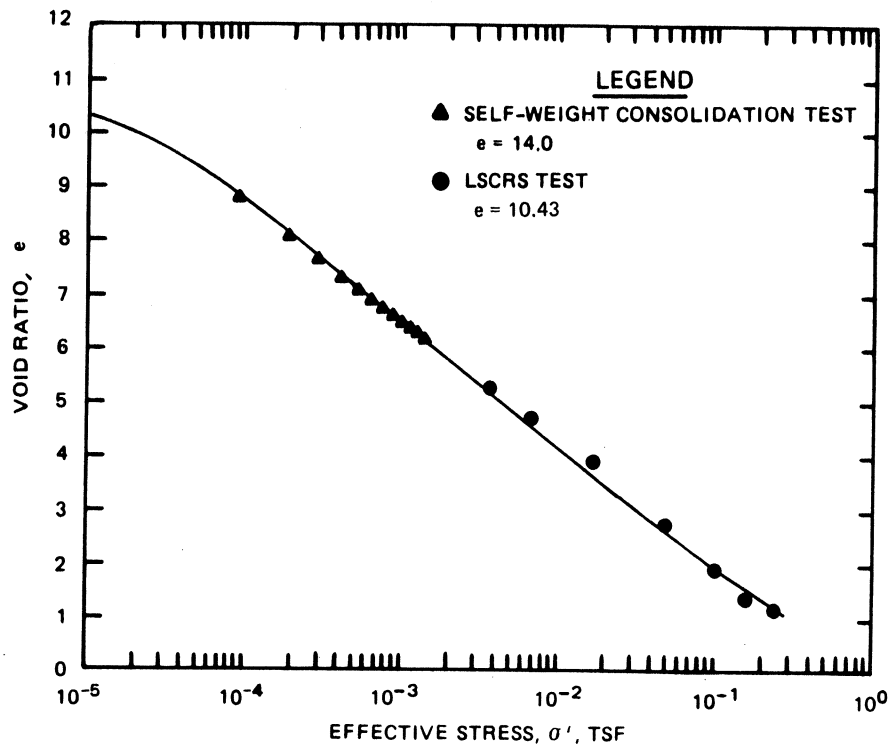


Figure 16. Void ratio-effective stress relationship, Dutch Kills

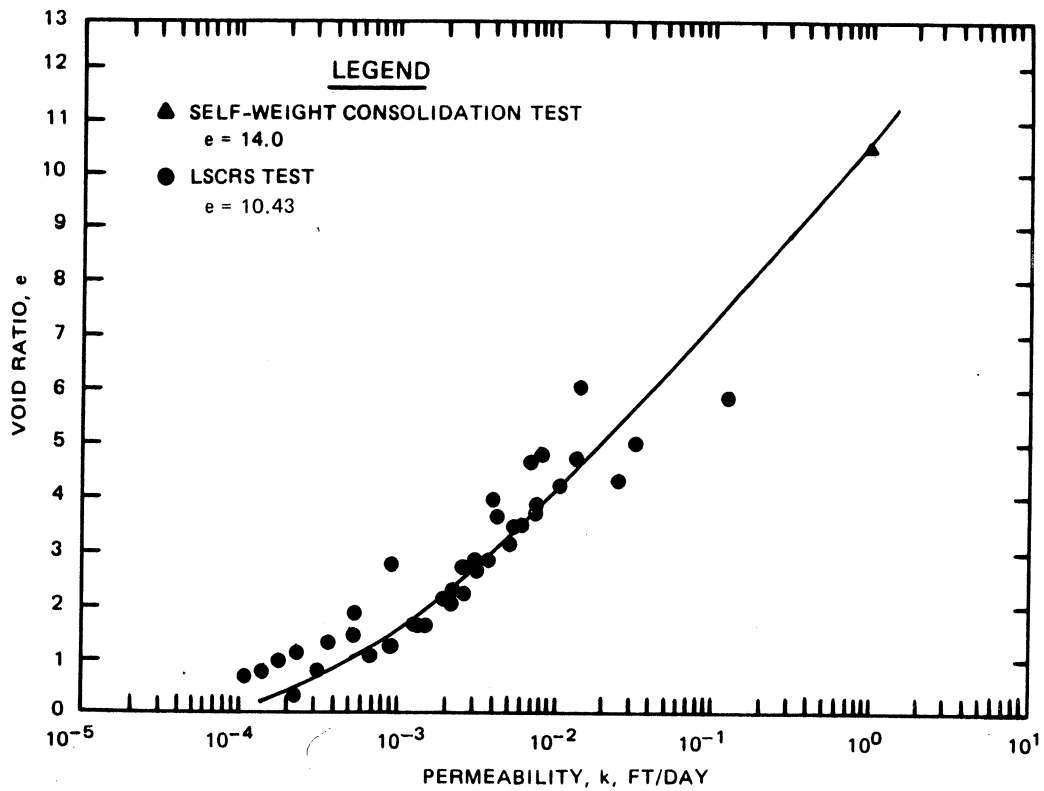


Figure 17. Void ratio-permeability relationship, Dutch Kills

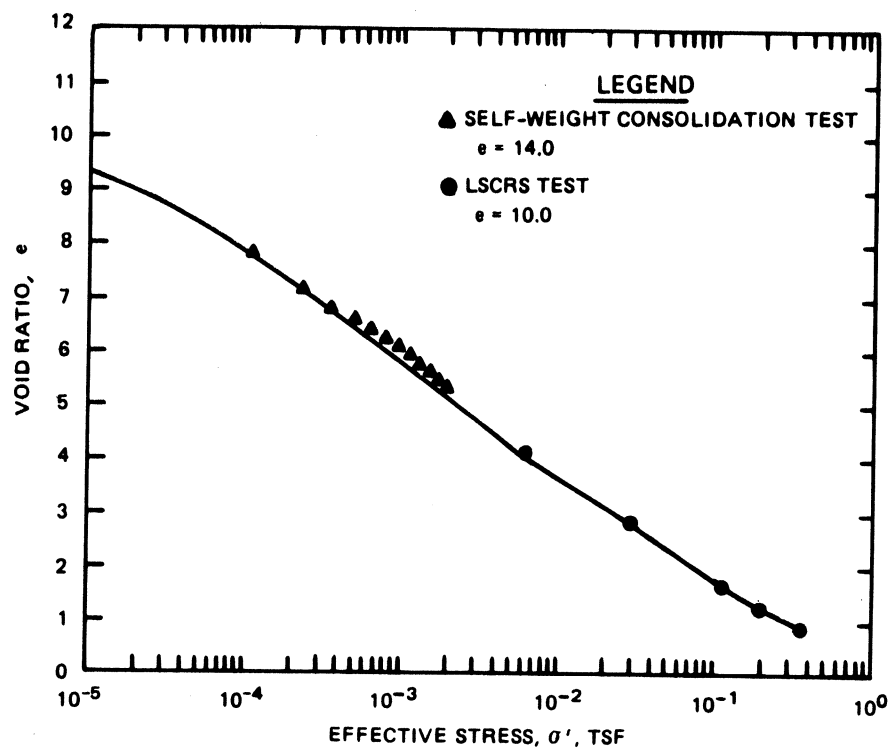


Figure 18. Void ratio-effective stress relationship, Port Authority

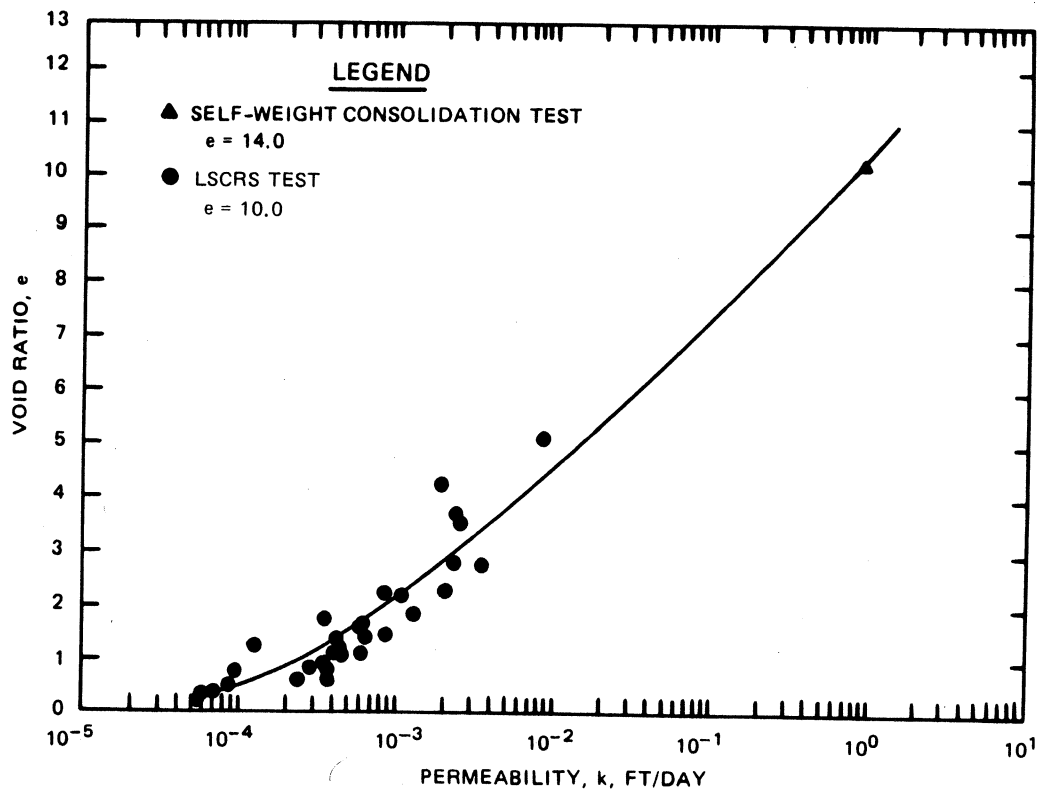


Figure 19. Void ratio-permeability relationship, Port Authority

PART IV: CONSOLIDATION/DEWATERING ANALYSIS

Approach

20. In order to predict the consolidation and dewatering behavior of the ten New York Harbor sediments, the laboratory test results discussed in Part III were utilized in a computerized mathematical model which accounts for both consolidation and desiccation. Analysis of results obtained from this model provides information on variation in dredged material surface elevation with time, reduction in void ratio (and thus water content) as consolidation and desiccation progress, and depth of dried crust.

Mathematical Model

Finite strain consolidation

21. The governing equation for finite strain consolidation theory is based on the continuity of fluid flow in a differential soil element, Darcy's law, and the effective stress principle, similar to the conventional consolidation theory (Gibson, England, and Hussey 1967). However, finite strain theory can additionally consider vertical equilibrium of the soil mass, place no restriction on the form of the stress-strain relationship, allow for variable coefficient of permeability, and accommodate any degree of strain.

The governing equation is:

$$\left(\frac{\gamma_s}{\gamma_w} - 1 \right) \frac{d}{de} \left[\frac{k(e)}{1+e} \right] \frac{\partial e}{\partial z} + \frac{\partial}{\partial z} \left[\frac{k(e)}{\gamma_w(1+e)} \frac{d\sigma'}{de} \frac{\partial e}{\partial z} \right] + \frac{\partial e}{\partial t} = 0$$

where γ_s = unit weight of solids

γ_w = unit weight of water

e = void ratio

$k(e)$ = soil permeability as a function of void ratio

z = vertical material coordinate measured against gravity

σ' = effective stress as a function of void ratio

t = time

This equation is well suited for the prediction of consolidation in thick deposits of very soft dredged materials since it accounts for the large strains and nonlinear soil properties inherent in these materials.

Desiccation

22. The removal of water by desiccation from a normally consolidating dredged material layer will result in formation of a surface crust; this in turn will cause additional consolidation due to the surcharge created by crust formation. Since surface drying may be significant between disposal operations, it is essential to incorporate predictions of desiccation settlement in evaluations of disposal site capacity.

23. An empirical description of the desiccation has been developed in terms of water balance in the upper portion of dredged material layers (Cargill 1985). Procedures for calculation of soil evaporation rates and depths of influence have been developed. Site-specific climatic conditions are incorporated in the analysis procedures. The predictive model developed utilizes void ratios instead of water contents in order to be compatible with the consolidation model.

Computer model

24. Both the finite strain consolidation model and the empirical desiccation model have been programmed for computer solution (Cargill 1985). The program Primary Consolidation and Desiccation of Dredged Fill (PCDDF) incorporates an explicit finite difference mathematical approximation to describe the consolidation process. Monthly adjustments in the top boundary condition and location are made to account for the amount of desiccation which has occurred. In addition to material settlement which comes from a calculation of void ratio distribution, the program also calculates the distribution of stresses and pore pressures throughout the dredged material layer.

Assumptions

25. The computer model of the consolidation/desiccation process is designed to be capable of analyzing very involved, or complicated, field situations. Therefore when general dredging and/or disposal operations are analyzed and specific details of the operations are not known, some assumptions are required. By making the assumptions reasonable and uniform in all cases

to be analyzed, comparisons can be made as to the relative performance of the various cases. The assumptions made in this analysis are discussed below.

Foundation soil conditions

26. The foundation soil was considered to be rigid and impermeable in all cases. The assumption of rigidity is without consequence since the ultimate storage capacity of the disposal site is not of concern in this study. The assumption of an impermeable foundation soil is necessary (a) for uniformity of the analyses, (direct comparison of sediment behaviors) since it is not known which sediment will be placed into each disposal area, and (b) since information on foundation soil permeabilities is not available. The assumption of an impermeable foundation will be conservative, or worst-case, since existence of a permeable foundation would allow drainage, and thus somewhat more rapid dewatering of the dredged material.

Dredging operations

27. For purposes of computer simulation, it was assumed that the dredging operation would begin in January for each sediment to be dredged. The assumption is significant only because the evaporative drying rates vary during different seasons of the year. The most effective drying period in the New York Harbor area is May to September, whereas no significant evaporative drying will occur during the period of November through March. If the sediment is allowed to dry for a period of one year, then the effect of timing of initiation of dredging is insignificant.

28. An additional assumption was made regarding the time which will elapse between initiation of disposal operations and decantation of ponded surface waters in the disposal site. A period of 90 days (3 months) was assumed in all cases for this study. Such a period of time allows for completion of dredging and gradual lowering of the weir crest elevation to allow removal of clarified surface water. Since specific information on particular dredging operations was not known during feasibility/planning studies and since this time has been found to be typical of such operations, the 90 day time period was used. The significance of this assumption is that the abscissa will need to be adjusted appropriately on any plots showing some variable as a function of "Time From Initiation of Disposal." The assumption made regarding placement of the dredged material was that the material was placed in a containment area at or above the water table. This assumption is necessary if any drying of the material is to be accomplished. If dredged

material is placed in a submerged containment area, the material below the water table will not dry although it will undergo consolidation and can subsequently be used as a foundation for other lifts of dredged material which will undergo both consolidation and desiccation.

Lift thickness

29. Three dredged material lift thicknesses which have been found to be typical of various disposal operations were utilized in this study. The lift thicknesses used in calculations were 3 ft, 5 ft, and 7 ft. By utilizing the same lift thicknesses for all sediments under study, comparisons of dewatering potential can be made between sediments. Because three different thicknesses were considered for any one sediment, the maximum depth of drying can be determined for each individual sediment.

Limits of drying

30. Values for the saturation limit, e_{SL} , and the desiccation limit, e_{DL} , for the sediments in this study were assumed since no specific data were available. By utilizing the values of liquid limit and plastic limit of the sediments under study, estimates of the average values of e_{SL} and e_{DL} were made. The value of e_{SL} was assumed to be 4.0 while e_{DL} was taken to be 1.5. These values are consistent with those determined from other field sites for similar dredged materials. The values of e_{SL} and e_{DL} are simply indicators of the void ratios of dredged materials at the end of first stage and second stage drying, respectively (Cargill 1985).

Climatological data

31. The monthly averages for rainfall and evaporation in the New York Harbor area were calculated. The rainfall data was obtained from the National Oceanic and Atmospheric Administration (1980) and was averaged for a period of 50 years. Evaporation data was averaged over a 30-year time period (Haliburton 1978). The data utilized in the analysis is shown in Table 4.

Results of Dewatering Analyses

32. In the following subsections, the results of the analyses are discussed for each sediment. Two figures are plotted for each of the New York Harbor sediments (except Lower Hackensack) in this section. For each sediment, both depth of dry material (as a percentage of initial lift thickness) and surface elevation are plotted against time (Figures 20-37). For the

Table 4
Climatological Data for New York Harbor Area

<u>Month</u>	<u>Rainfall, inches</u>	<u>Pan Evaporation, inches</u>
January	3.31	0.00
February	3.02	0.00
March	3.94	0.00
April	3.58	1.92
May	3.51	4.80
June	3.42	4.92
July	3.77	5.88
August	4.23	3.84
September	3.63	4.68
October	3.07	1.92
November	3.53	0.00
December	3.45	0.00

dewatering analysis the value of e_{DL} of 1.5 corresponds to a moisture content within the dried material of approximately 60 percent. Dredged material at this water content should be acceptable for use as sanitary landfill cover. It should be noted that this water content was determined from empirical relationships between void ratio and moisture content within the dried dredged material crust and must therefore be considered to be an approximate value.

Lower Hackensack

33. Because this sediment was non-plastic (USCS classification of NP), it will not undergo consolidation and therefore was not subjected to consolidation testing. This sediment should dewater rapidly because of its granular (coarse-grained) composition. In order to dry this material, the weir crest elevation should be gradually lowered to allow drainage of the water ponded above and within the dredged material. This operation will leave the material in a moist, but not saturated, condition; therefore it should be available for use as landfill cover shortly after drainage of the containment area has been completed.

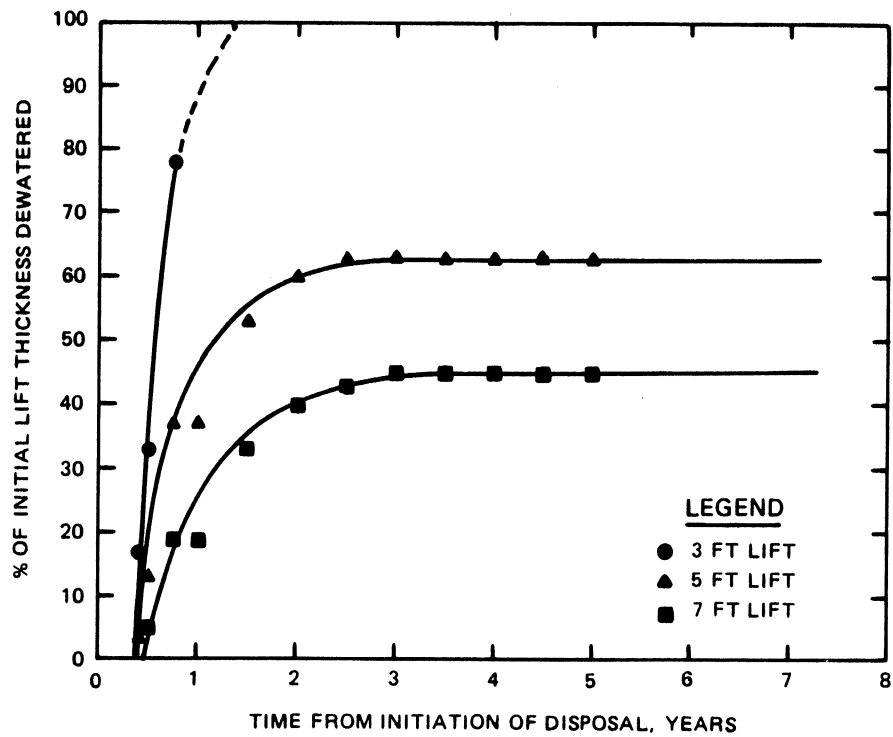


Figure 20. Depth of dry material as a function of lift thickness and time for Lower Passaic

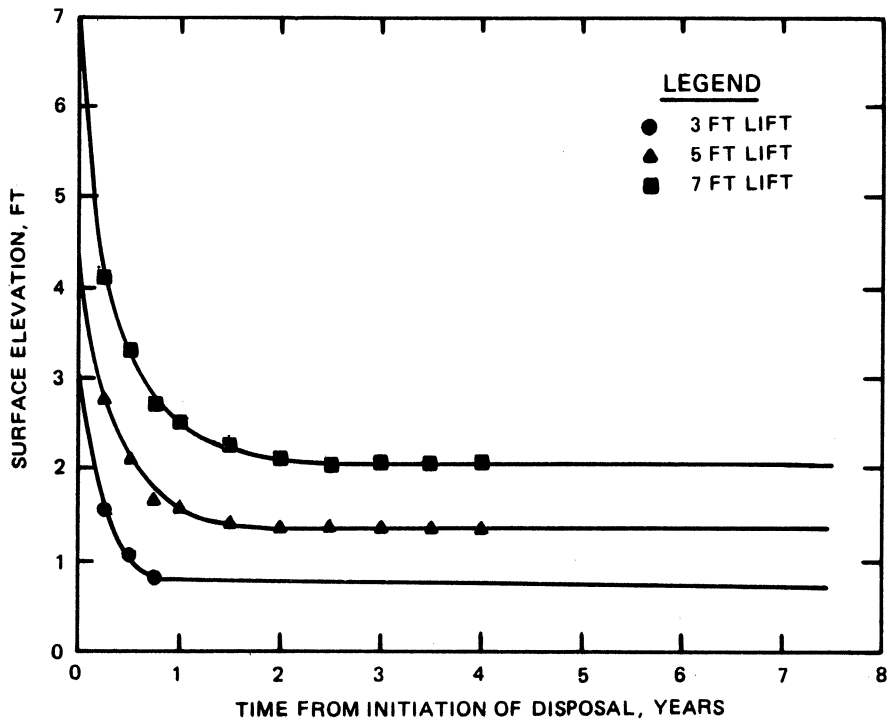


Figure 21. Dredged material surface elevation as a function of lift thickness and time for Lower Passaic

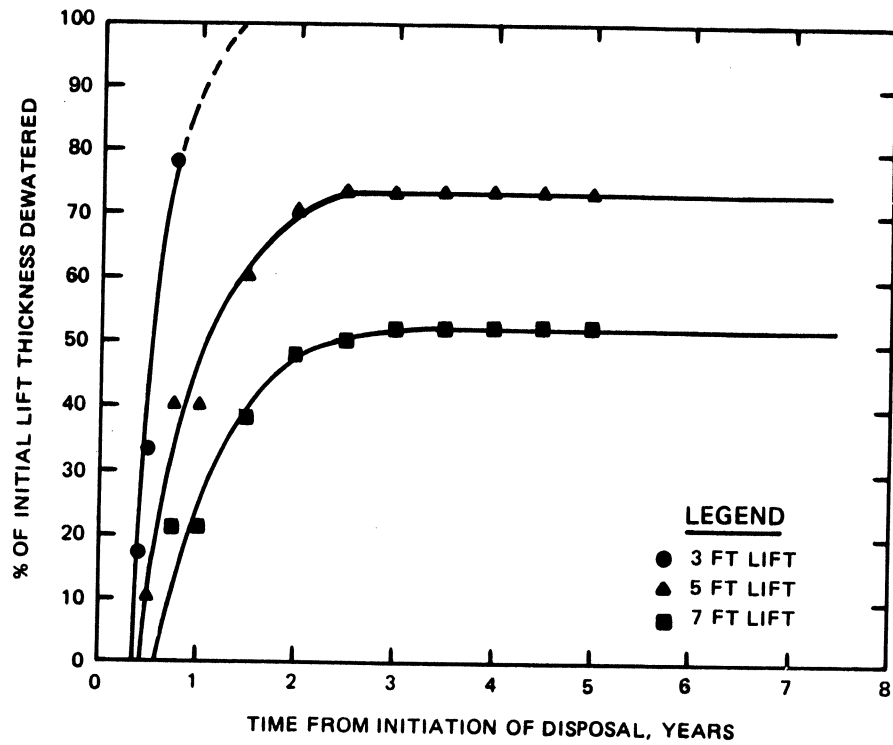


Figure 22. Depth of dry material as a function of lift thickness and time for Port Elizabeth

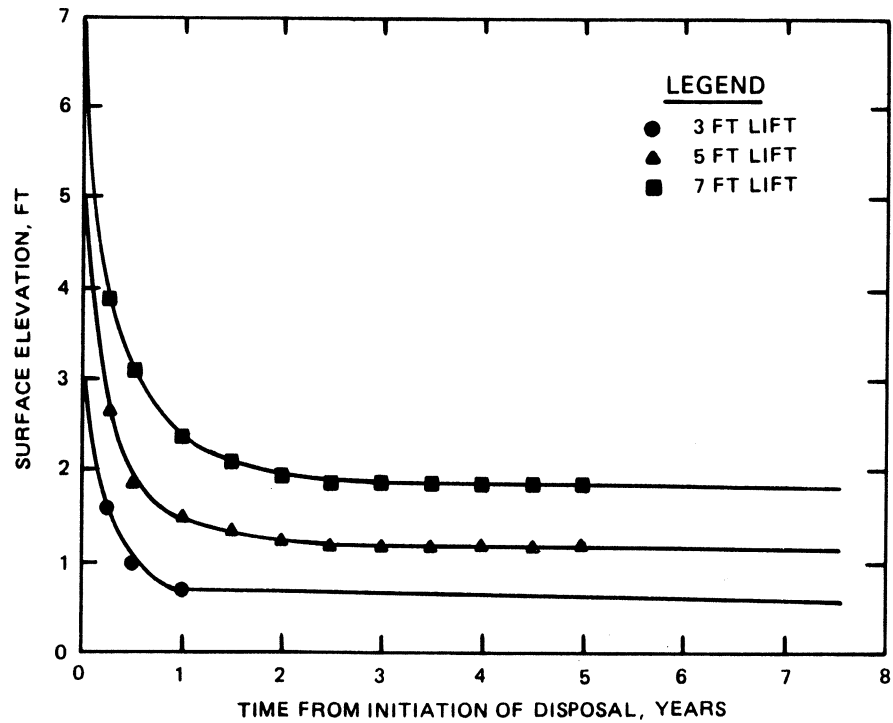


Figure 23. Dredged material surface elevation as a function of thickness and time for Port Elizabeth

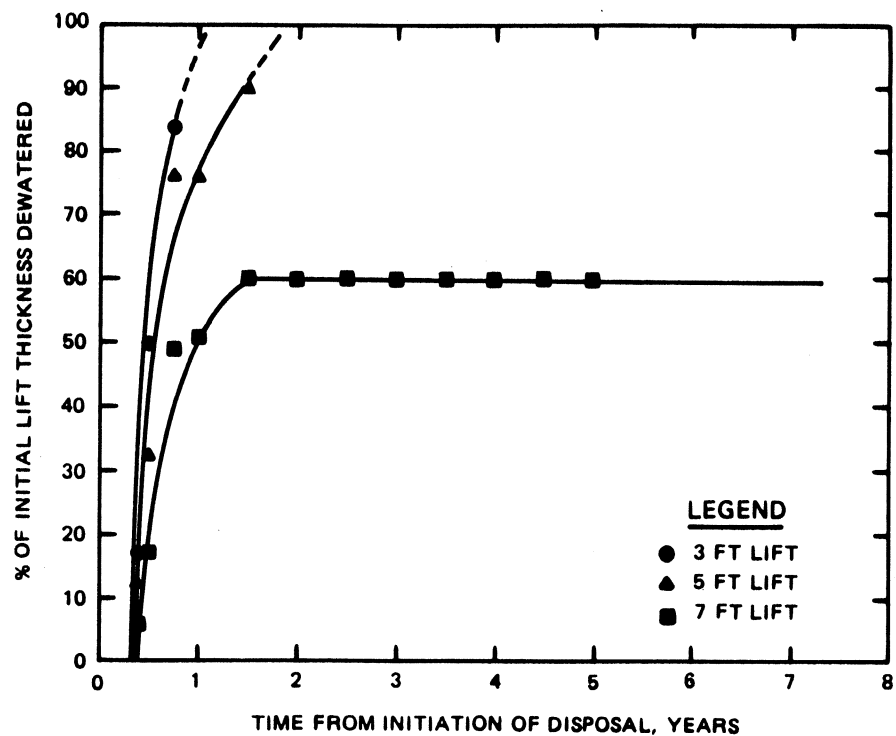


Figure 24. Depth of dry material as a function of lift thickness and time for Newark Bay

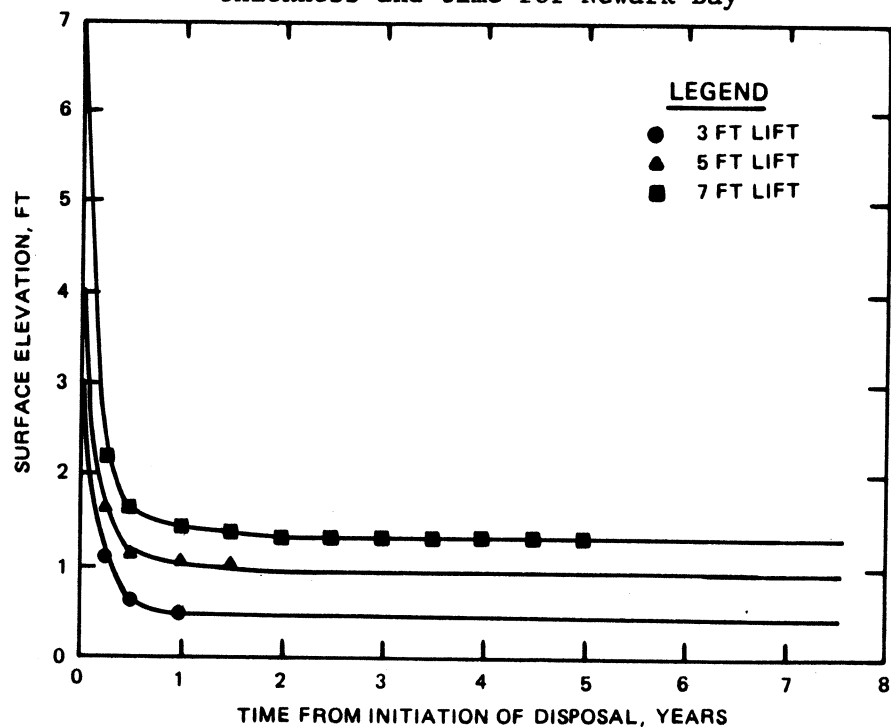


Figure 25. Dredged material surface elevation as a function of lift thickness and time for Newark Bay

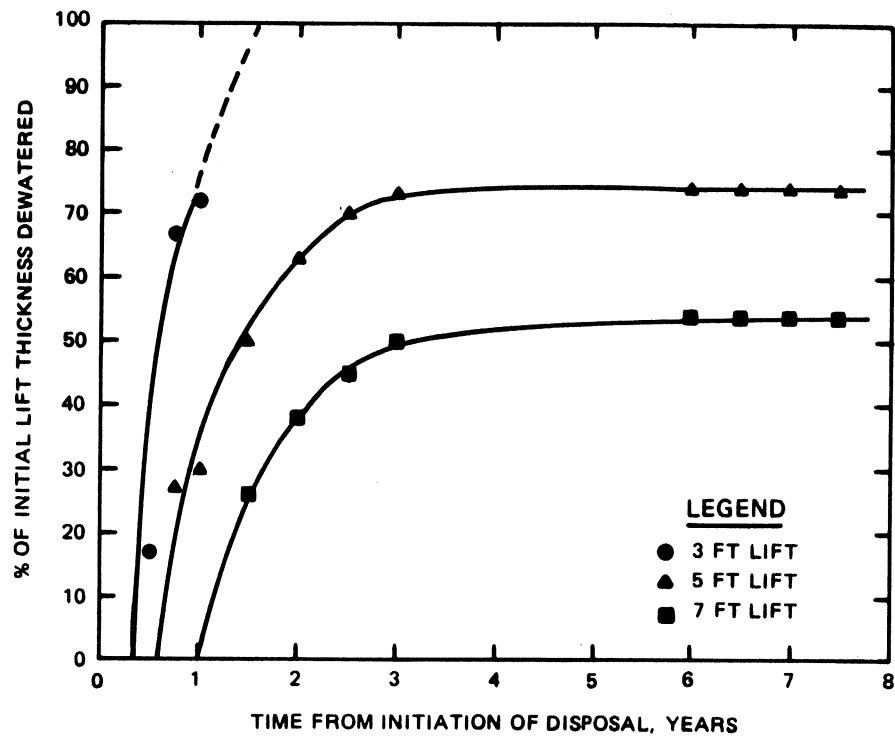


Figure 26. Depth of dry material as a function of lift thickness and time for US Metals

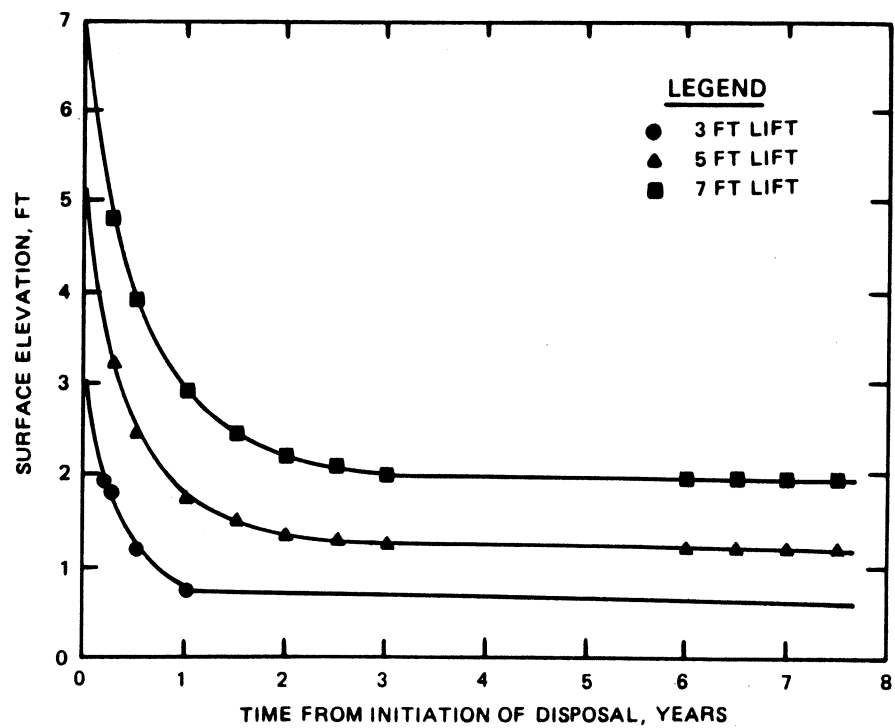


Figure 27. Dredged material surface elevation as a function of thickness and time for US Metals

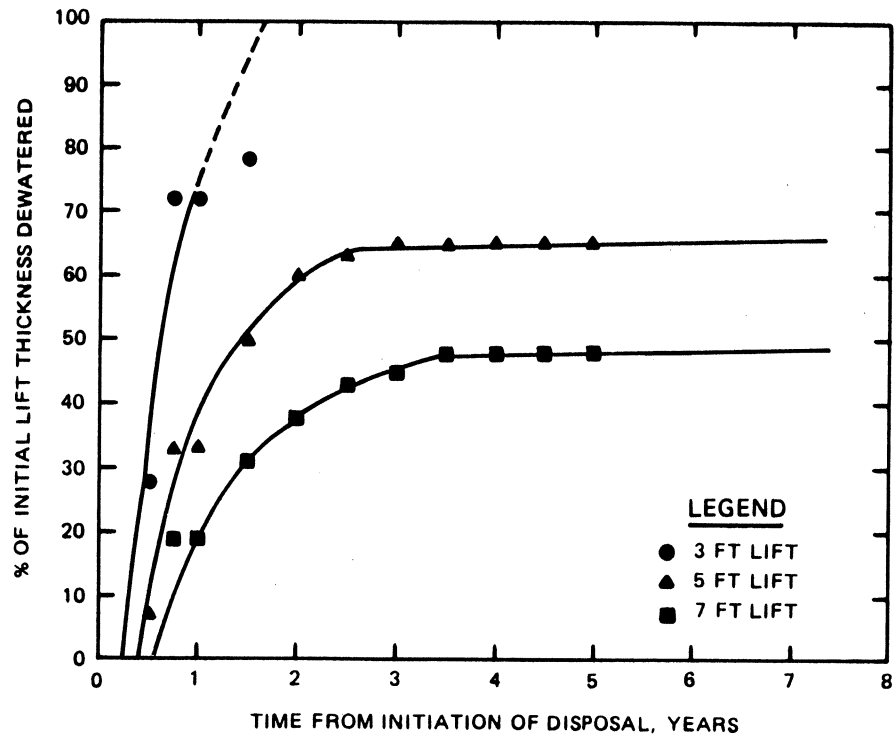


Figure 28. Depth of dry material as a function of lift thickness and time for Seguin Point

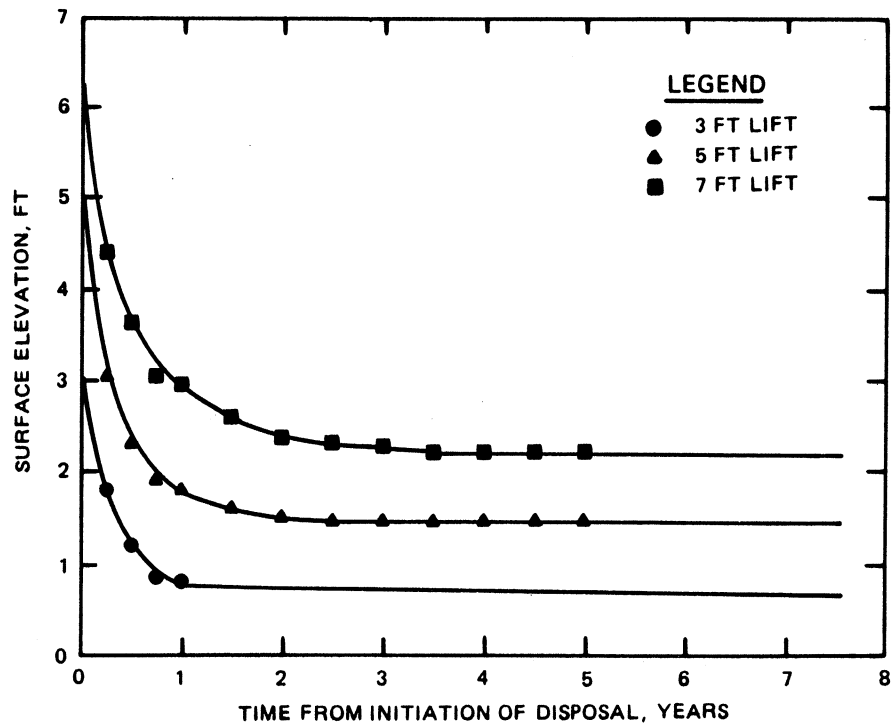


Figure 29. Dredged material surface elevation as a function of lift thickness and time for Seguin Point

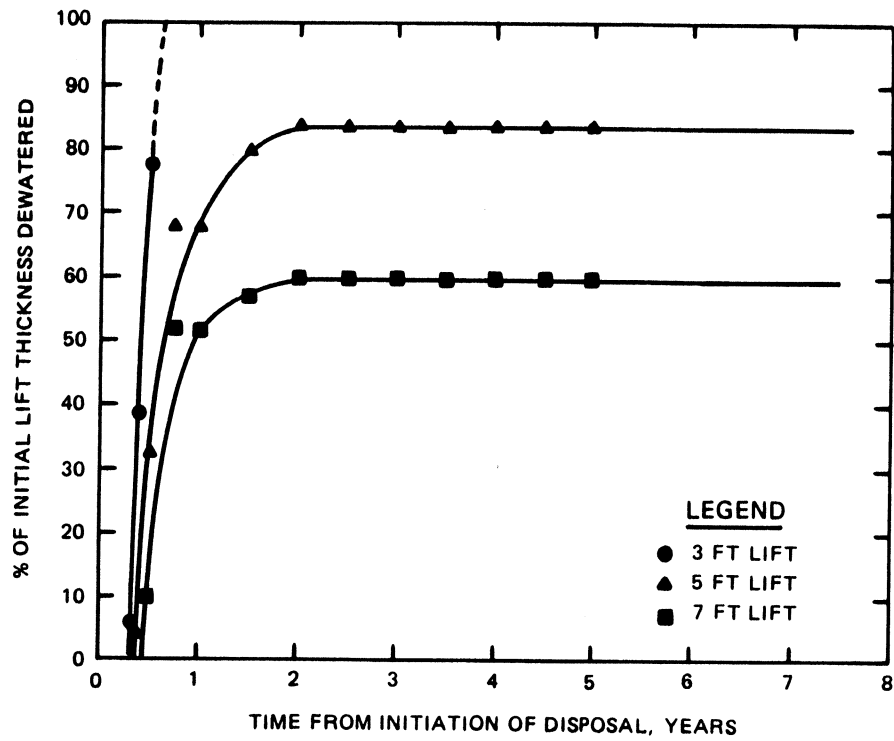


Figure 30. Depth of dry material as a function of lift thickness and time for Earle Navy

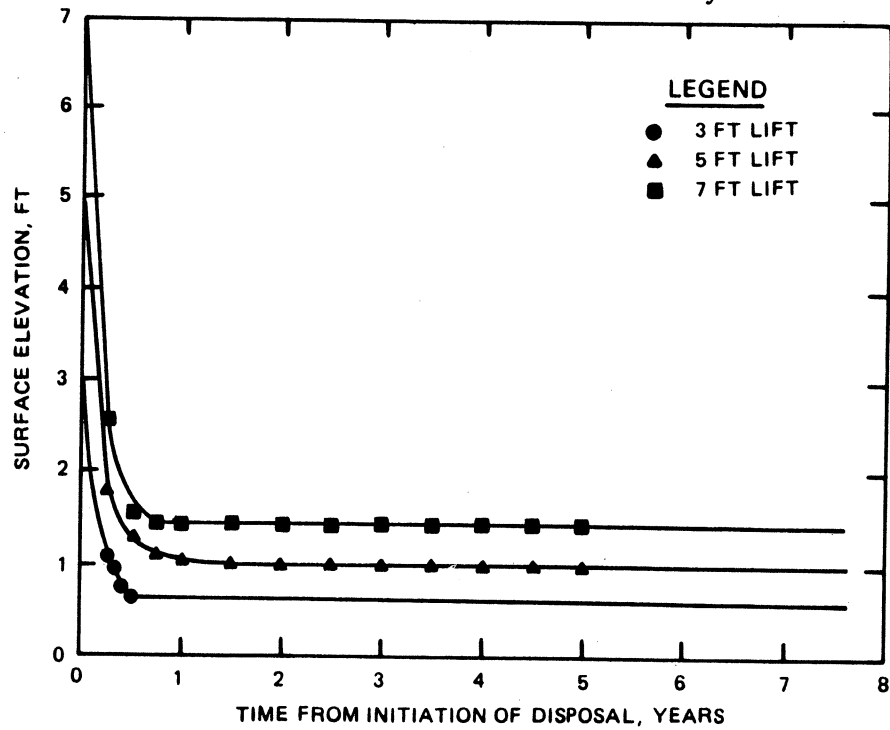


Figure 31. Dredged material surface elevation as a function of lift thickness and time for Earle Navy

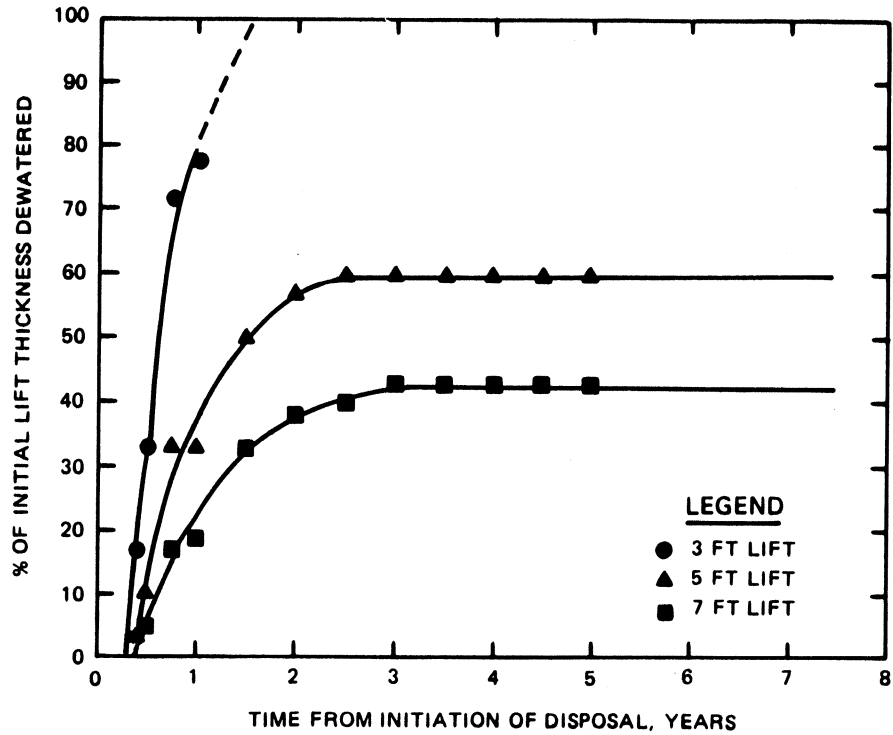


Figure 32. Depth of dry material as a function of lift thickness and time for Red Hook

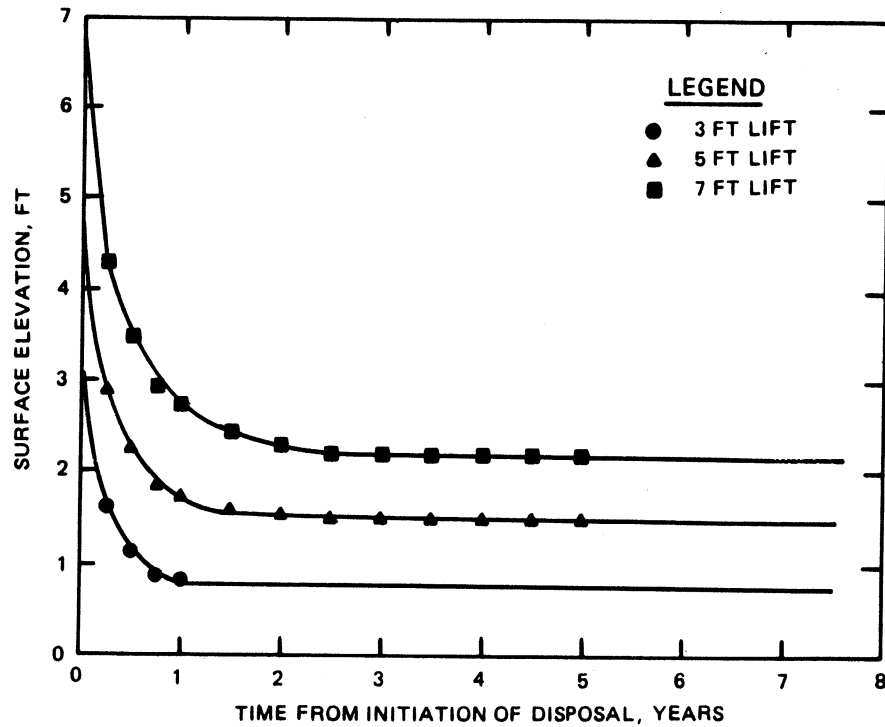


Figure 33. Dredged material surface elevation as a function of lift thickness and time for Red Hook

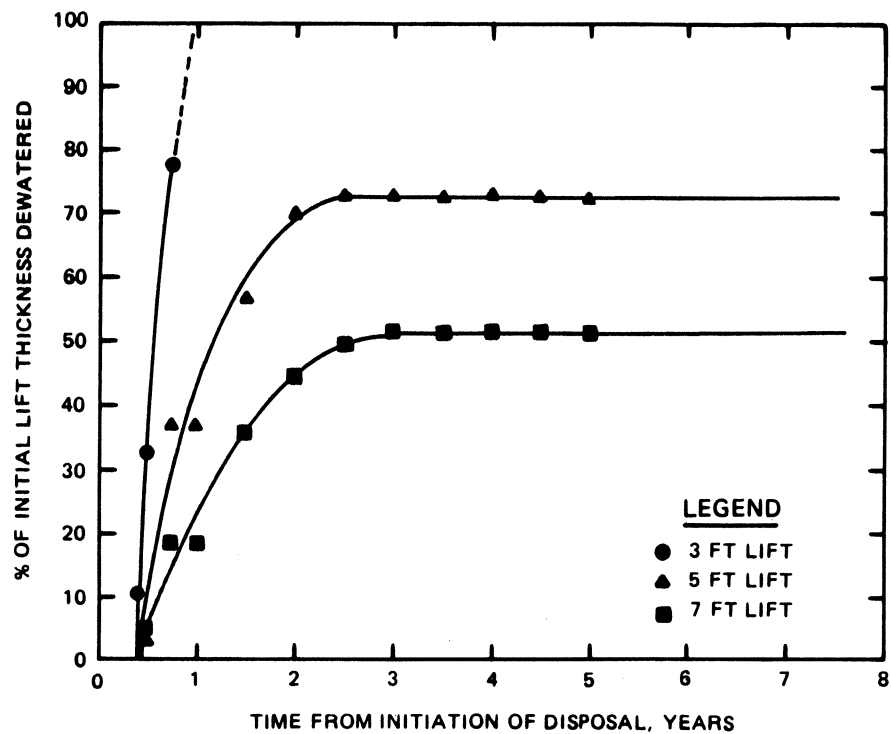


Figure 34. Depth of dry material as a function of lift thickness and time for Dutch Kills

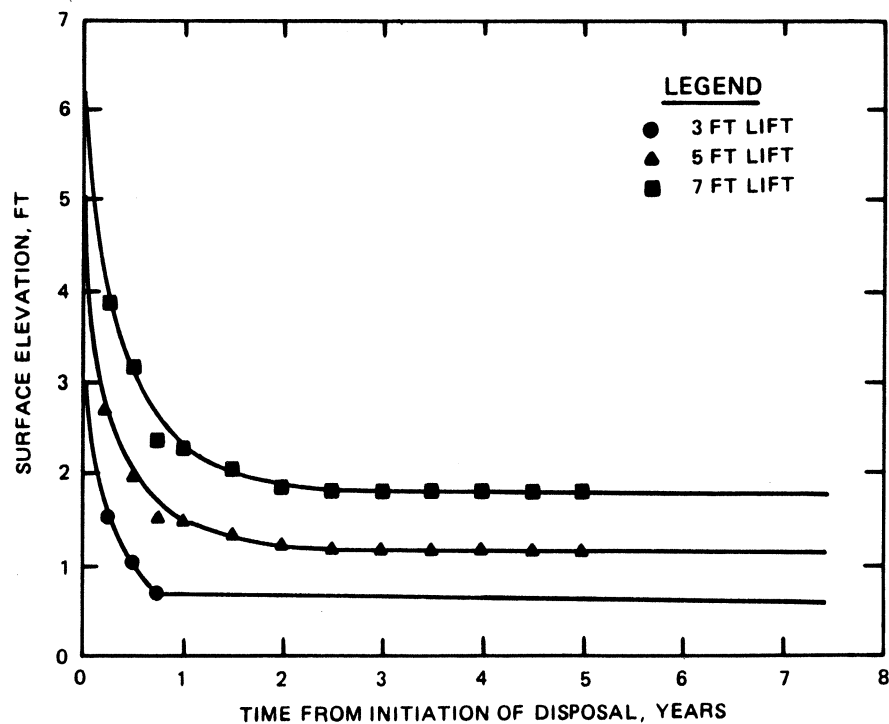


Figure 35. Dredged material surface elevation as a function of lift thickness and time for Dutch Kills

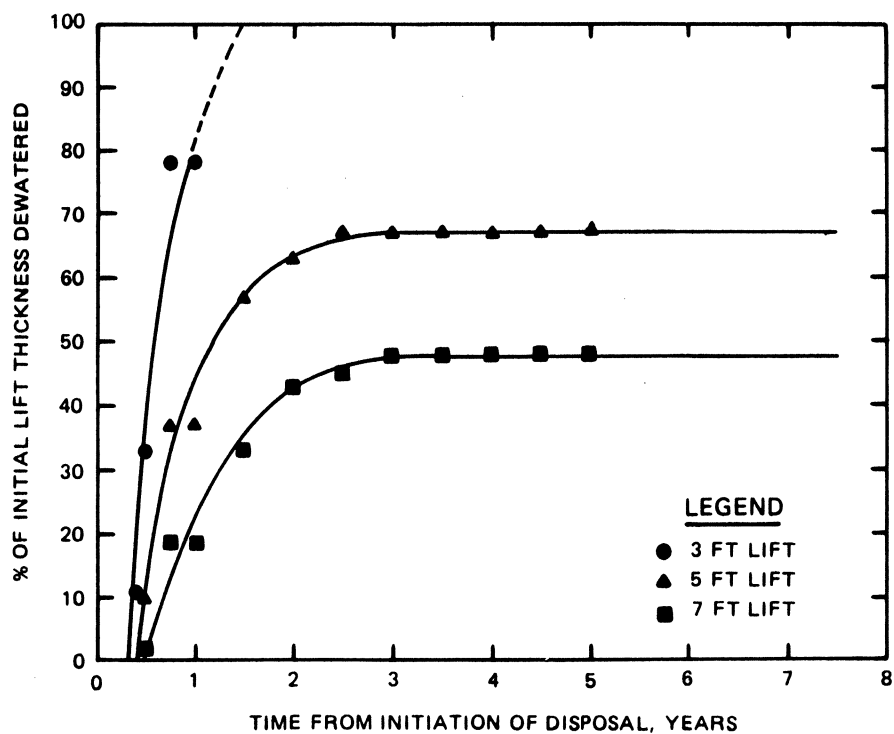


Figure 36. Depth of dry material as a function of lift thickness and time for Port Authority

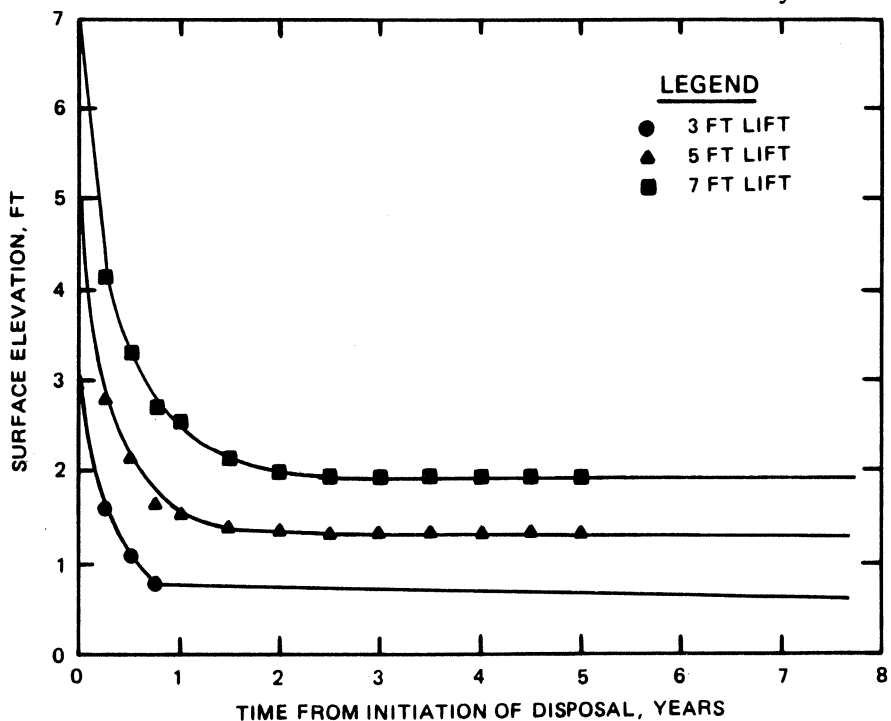


Figure 37. Dredged material surface elevation as a function of lift thickness and time for Port Authority

Lower Passaic

34. The Lower Passaic sediments exhibited a minimum depth for dewatering of approximately 3.1 ft (Figure 20). This was evidenced by the complete drying of the 3 ft lift of material as well as the ultimate drying of 63 percent or 3.15 ft of the 5 ft lift and 43 percent or 3.01 ft of the 7 ft lift. These depths of drying represent percentages of initial lift thickness; they do not indicate actual depths of dry material. Therefore if it is desired to have a lift of dredged material dried throughout its depth, the initial thickness of the dredged material should not exceed about 3 ft. Drying of a 3 ft lift (initial thickness) of dredged material will result in a final depth of dry material of approximately 10 inches. This would provide approximately 36,300 ft³ of dried material per acre.

35. A 3 ft lift of Lower Passaic sediment would be dried throughout approximately 80 percent of its depth at the end of one summer drying period. Because evaporation decreases markedly in the other portions of the year, drying of the remaining 20 percent of the 3 ft lift would probably not be accomplished until the next year's drying period.

Port Elizabeth

36. The Port Elizabeth sediment exhibited a maximum depth for dewatering of approximately 3.65 ft. As shown in Figure 22, this was evidenced by the ultimate drying of 73 percent or 3.65 ft of the 5 ft lift and 52 percent or 3.64 ft of the 7 ft lift. The 3 ft lift dried throughout its depth. Again, these depths of drying represent percentages of initial lift thickness; they do not indicate actual depths of dry material.

37. If it is desired to place a lift of dredged material which will dry throughout its depth, the initial thickness of the lift should not exceed about 3.65 ft. Drying of 3.65 ft lift (initial thickness) of dredged material will result in a final depth of dry material of approximately 9.4 inches. This would provide approximately 34,125 ft³ dried material per acre.

38. A 3 ft lift of Port Elizabeth sediment would be dried throughout approximately 80 percent of its depth at the end of one summer drying period. Because evaporation decreases markedly in the other portions of the drying of the remaining 20 percent of the 3 ft lift would probably not be accomplished until the following year's drying period.

Newark Bay

39. The Newark Bay sediment exhibited a maximum depth for dewatering of approximately 5.0 ft (Figure 24). This was evidenced by the complete drying of both the 3 ft and the 5 ft lifts. The ultimate drying of the 7 ft lift proceeded 60 percent or 4.2 ft into the 7 ft lift. It is suggested that the difference in depth of drying in the 5 ft and 7 ft layers is related to the permeability and capillarity of this sandy material; it may also result in part from the formulation of the computer code. These depths of drying are once again percentages of initial lift thickness; they do not indicate actual depths of dry material.

40. If it is desired to place a lift of dredged material which will dry throughout its depth, the initial thickness of the lift should not exceed about 5.0 ft. Drying of a 5.0 ft lift (initial thickness) of dredged material will result in a final depth of dry material of approximately 11.2 inches. This would provide approximately 40,650 ft³ of dried material per acre.

41. A 5 ft lift of Newark Bay sediment would be dried throughout approximately 70 percent of its depth at the end of one summer drying period. Because evaporation decreases markedly in the other portions of the year, drying of the remaining 30 percent of the 5 ft lift would probably not be accomplished until the following year's drying period.

US Metals

42. The US Metals sediment exhibited a maximum depth for dewatering of approximately 3.75 ft (Figure 26). This was evidenced by the ultimate drying of 74 percent or 3.70 ft of the 5 ft lift and 54 percent or 3.78 ft of the 7 ft lift. The 3 ft lift dried throughout its depth. These depths of drying are percentages of initial lift thickness; they do not indicate actual depths of dry material.

43. If it is desired to place a lift of dredged material which will dry throughout its depth, the initial thickness of the lift should not exceed about 3.75 ft. Drying a 3.75 ft lift (initial thickness) of dredged material will result in a final depth of dry material of approximately 9.4 inches. This would provide approximately 34,125 ft³ of dried material per acre.

44. A 3.75 ft lift of US Metals sediment would be dried throughout approximately 50 percent of its depth at the end of one summer drying period. Because evaporation decreases markedly in the other portions of the year,

drying of the remaining 50 percent of the 3.75 ft lift would probably not be accomplished until the following year's drying period.

Seguine Point Bend

45. The Seguine Point sediment exhibited a maximum depth of drying of approximately 3.35 ft (Figure 28). This was evidenced by the ultimate drying of 67 percent or 3.35 ft of the 5 ft lift and 48 percent or 3.36 ft of the 7 ft lift. The 3 ft lift dried throughout its depth. These depths of drying are percentages of initial lift thickness; they do not indicate actual depths of dry material.

46. If it is desired to place a lift of dredged material which will dry throughout its depth, the initial thickness of the lift should not exceed about 3.35 ft. Drying of a 3.35 ft lift (initial thickness) of dredged material will result in a final depth of dry material of approximately 8.65 inches. This would provide approximately $31,415 \text{ ft}^3$ of dried material per acre.

47. A 3.35 ft lift of Seguine Point sediment would be dried throughout approximately 45 percent of its depth at the end of one summer drying period. Because evaporation decreases markedly in the other portions of the year, drying of the remaining 55 percent of the 3.35 ft lift would probably not be accomplished until the following year's drying period.

Earle Navy

48. The Earle Navy sediment exhibited a maximum depth of drying of 4.20 ft (Figure 30). This was evidenced by the ultimate drying of 84 percent or 4.20 ft of the 5 ft lift and 60 percent or 4.20 ft of the 7 ft lift. The 3 ft lift dried throughout its depth. These depths of drying are percentages of initial lift thickness; they do not indicate actual depths of dry material.

49. If it is desired to place a lift of dredged material which will dry throughout its depth, the initial thickness of the lift should not exceed about 4.20 ft. Drying of a 4.20 ft lift (initial thickness) of dredged material will result in a final depth of dry material of approximately 10.4 inches. This would provide approximately $37,750 \text{ ft}^3$ of dried material per acre.

50. A 4.20 ft lift of Earle Navy sediment would be dried throughout approximately 70 percent of its depth at the end of one summer drying period. Because evaporation decreases markedly in the other portions of the year,

drying of the remaining 30 percent of the 4.20 ft lift would probably not be accomplished until the following year's drying period.

Red Hook Channel

51. The Red Hook sediment exhibited a maximum depth of drying of 3.0 ft (Figure 32). This was evidenced by complete drying of the 3 ft lift as well as the ultimate drying of 60 percent or 3.0 ft of the 5 ft lift and 43 percent or 3.0 ft of the 7 ft lift. These depths of drying are percentages of initial lift thickness; they do not indicate actual depths of dry material.

52. If it is desired to place a lift of dredged material which will dry throughout its depth, the initial thickness of the lift should not exceed about 3.0 ft. Drying of a 3.0 ft lift (initial thickness) of dredged material will result in a final depth of dry material of approximately 9.47 inches. This would provide approximately 34,385 ft³ of dried material per acre.

53. A 3.0 ft lift of Red Hook sediment would be dried throughout approximately 72 percent of its depth at the end of one summer drying period. Because evaporation decreases markedly in the other portions of the year, drying of the remaining 28 percent of the 3.0 ft lift would probably not be accomplished until the following year's drying period.

Dutch Kills

54. The Dutch Kills sediment exhibited a maximum depth of drying of approximately 3.65 ft (Figure 34). This was evidenced by the ultimate drying of 73 percent or 3.65 ft of the 5 ft lift and 52 percent or 3.64 ft of the 7 ft lift. The 3 ft lift dried throughout its depth. These depths of drying are percentages of initial lift thickness; they do not indicate actual depths of dry material.

55. If it is desired to place a lift of dredged material which will dry throughout its depth, the initial thickness of the lift should not exceed about 3.65 ft. Drying of a 3.65 ft lift (initial thickness) of dredged material will result in a final depth of dry material of approximately 9.4 inches. This would provide approximately 34,125 ft³ of dried material per acre.

56. A 3.65 ft lift of Dutch Kills sediment would be dried throughout approximately 50 percent of its depth at the end of one summer drying period. Because evaporation decreases markedly in the other portions of the year, drying of the remaining 50 percent of the 3.65 ft lift would probably not be accomplished until the following year's drying period.

Port Authority NY/NJ Terminals

57. The Port Authority sediment exhibited a maximum depth of drying of approximately 3.35 ft (Figure 36). This was evidenced by the ultimate drying of 67 percent or 3.35 ft of the 5 ft lift and 48 percent or 3.36 ft of the 7 ft lift. The 3 ft lift dried throughout its depth. These depths of drying are percentages of initial lift thickness; they do not indicate actual depths of dry material.

58. If it is desired to place a lift of dredged material which will dry throughout its depth, the initial thickness of the lift should not exceed about 3.35 ft. Drying of the 3.35 ft lift (initial thickness) of dredged material will result in a final depth of dry material of approximately 9.45 inches. This would provide approximately 34,300 ft³ of dried material per acre.

59. A 3.35 ft lift of Port Authority sediment would be dried throughout approximately 60 percent of its depth at the end of one summer drying period. Because evaporation decreases markedly in the other portions of the year, drying of the remaining 40 percent of the 3.35 ft lift would probably not be accomplished until the following year's drying period.

Comparison of sediments

60. Table 5 presents a comparison of the 10 New York Harbor sediments. This table shows the depth of drying calculated as a percentage of initial lift thickness, final thickness of dry material, and the ultimate yield of dry material per acre of containment area.

Table 5
Comparison of Sediment Dewatering Characteristics

<u>Sediment</u>	<u>Depth of Drying (% Initial Lift) ft</u>	<u>Thickness of Dry Material in.</u>	<u>Yield per Acre ft³</u>
Lower Hackensack	(Throughout lift)	--	--
Lower Passaic	3.1	10.0	36,300
Port Elizabeth	3.65	9.4	34,125
Newark Bay	5.0	11.2	40,650
US Metals	3.75	9.4	34,125
Seguine Point Bend	3.35	8.65	31,415
Earle Navy	4.20	10.4	37,750
Red Hook Channel	3.00	10.4	37,735
Dutch Kills	3.65	9.4	34,125
Port Authority	3.35	9.45	34,300

PART V: CONCLUSIONS

Sediment Dewatering

61. Based upon the preceding discussions of the dewatering analyses, it is evident that the sediments analyzed in this study can be dewatered to their maximum depth within a period of approximately 2 years in most cases. The maximum depth to which a sediment may be dewatered by evaporative drying varies somewhat depending upon the properties of the particular sediment. This depth ranges from 3.35 ft to 5.0 ft except in the case of the Lower Hackensack sediment which will probably dry throughout the depth of deposit. Quantities of dried material available for use as sanitary landfill cover vary from 31,415 ft³ per acre to 40,650 ft³ per acre, or the quantity of Lower Hackensack sediment deposited per acre.

62. The sediments reach various degrees of dewatering after the first summer evaporative drying cycle. Lower Hackensack would probably be dried throughout 100 percent of its depth. The Port Authority sediment would be dried throughout 60 percent of its depth. Both the US Metals and Dutch Kills sediments would be dried throughout 50 percent of their depths while the Seguine Point sediment would be dried throughout only 45 percent of its depth. All other sediments would dry throughout 70 to 80 percent of their depths at the end of one summer drying cycle.

63. The sediments may be ranked in order of their dewaterability based upon either the rate of dewatering or upon the ultimate quantity of dry material which will be produced. Although the latter will probably be most useful, the sediments were ranked each way. Table 6 shows the ranking of sediments by their respective rates of dewatering, while Table 7 shows the ranking based upon quantities of dry material produced.

64. Comparison of Tables 6 and 7 indicates that the Lower Hackensack sediment will be most quickly and completely dewatered. The US Metals, Dutch Kills and Seguine Point sediments are ranked lowest according to both methods. There is a certain amount of similarity in the ranking of sediments shown in Table 6 and 7. The only sediments which were changed in their relative rankings were Lower Passaic and Port Elizabeth. Lower Passaic moved from No. 2 when ranked according to rate of drying to the No. 4 position according to

Table 6
Ranking of Sediments by Rate of Dewatering

<u>Ranking</u>	<u>Sediment</u>	<u>Thickness Dry at End of First Season, %</u>	<u>Depth of Dry Material After First Season, in.</u>	<u>Ultimate Depth of Dry Mate- rial, in.</u>
1	Lower Hackensack	100	--	--
2	Lower Passaic	80	8.00	10.0
3	Newark Bay	70	7.84	11.2
4	Port Elizabeth	80	7.52	9.4
5	Earle Navy	70	7.28	10.4
6	Red Hook Channel	72	6.82	9.47
7	Port Authority	60	5.67	9.45
8	US Metals	50	4.70	9.4
9	Dutch Kills	50	4.70	9.4
10	Seguine Point Bend	45	3.89	8.65

Table 7
Ranking of Sediments by Quantity of Dry Material Produced

<u>Ranking</u>	<u>Sediment</u>	<u>Ultimate Thickness of Dry Material, in.</u>	<u>Yield per Acre ft³</u>
1	Lower Hackensack	--	--
2	Newark Bay	11.2	40,650
3	Earle Navy	10.4	37,750
4	Lower Passaic	10.0	36,300
5	Red Hook Channel	9.47	34,385
6	Port Authority	9.45	34,300
7	Port Elizabeth	9.4	34,125
8	US Metals	9.4	34,125
9	Dutch Kills	9.4	34,125
10	Seguine Point Bend	8.65	31,415

ultimate quantity of dry material produced. Port Elizabeth moved from No. 4 by rate of dewatering to No. 7 quantity of dry material.

Dewatering Disposal Sites

65. For maximum efficiency and economy of the dredged material dewatering operation, consideration must be given to the dewatering characteristics of the sediments, location of material to be dredged with respect to the disposal site, and proximity of the disposal site to the potential user of the dried material, i.e. the sanitary landfill, as well as to the characteristics and conditions existing in the disposal site.

66. Each disposal operation which is undertaken should be managed so that disposal of dredged material results in thin lift placement. Thin lifts are generally considered to be no more than 3 ft to 5 ft at completion of the disposal operation. Lift thicknesses of this depth range were found in this study to be the maximum depth of dredged material which could be completely dewatered by evaporative drying.

67. The quantity of a particular sediment which is placed into a specific disposal area should be controlled, for maximum efficiency of dewatering, so that the resulting lift thickness does not exceed the maximum dewatering depth for that sediment. The quantity of sediment which can be placed into a specific disposal area, while meeting the above mentioned criteria may be calculated as follows:

$$V_c = 1633.33 HA \frac{1 + e_c}{1 + e_{oo}}$$

where V_c = volume of sediment in channel to be dredged, yd^3
 H = dredged material lift thickness in disposal site, ft
 A = surface area of disposal site, acres
 e_c = void ratio of sediment in channel
 e_{oo} = void ratio of sediment in disposal site at beginning of consolidation

68. In the following subsections, the suitability of the individual disposal sites for use as dredged material dewatering sites will be discussed.

Site N37

69. As a dewatering disposal site, N37 would be a good site. Although it may contain wetlands, it seems to be roughly at or above sea level. This means that almost all dredged material placed in this site could be subjected to evaporative drying since only a relatively small quantity would be below water level. Also, the size of the site (approximately 155 acres) makes it viable for thin lift placement of considerable quantities of dredged material. The major problems with this site would seem to be (a) the political aspects regarding presence of wetlands and (b) presence of the Public Service Gas and Electric Company's 16-inch gas transmission main.

Site N61

70. This 82-acre site would be good for a dredged material dewatering site if the associated political questions can be resolved. The site does contain some tidal wetlands along the eastern perimeter which would result in placement of some dredged material that would not be subjected to evaporative drying; this should be a minimal amount of material. Since this site is subjected to periodic flooding during storm events, the confining dikes constructed at this site should be designed to prevent entrance of storm water into the dewatering site.

Site L13

71. Although this site (48 acres) is somewhat smaller than the other dewatering sites considered in this study, it is considered to be a good site from the standpoint of location and elevation. The site does contain some tidal flats, but once again the major portion of the dredged material placed in this site would be subjected to dewatering forces. The quantity of dredged material placed in this site during a specific disposal operation should be more limited than at the other sites if total dewatering of the material is desired.

Site N30

72. This site is considered to have a total of 64 acres which are available for dewatering of dredged material. This site should be suitable for use as a dewatering disposal site. No particular problems are noted for this site.

Raritan Center

73. This site would be excellent as a regional dewatering site. Because of the size of this site (approximately 740 acres), this site could be managed

very effectively and efficiently for dewatering of dredged material. The site could be compartmentalized to allow periodic disposal into each of the compartments with subsequent drying of the dredged material in adjacent compartments. The location of this site in close proximity to both the ILR Landfill and the Edison Town Landfill makes it ideal as a supply of sanitary landfill cover. The major problem with this site is the political determination of whether the site contains wetlands. Any engineering problems associated with dewatering of dredged material in a wet environment would be minimal; only a relatively small quantity of the dredged material would be adversely affected in its dewatering.

Newark Bay

74. This 165-acre site is located in a subaqueous environment. Large quantities of dredged material could be contained in this site before the dredged material surface emerges above the water surface. Therefore, although this site would be excellent as a dredged material containment area, it would not be suitable as a dredged material dewatering site at the present time. After the dredged material surface has risen to the point that some dredged material can undergo evaporative drying, significant problems with removal of the dried material would probably be encountered since the material under the dried crust would be in a soft condition. This would not necessarily be the case if some of the granular dredged materials were placed in this site, but it would necessitate sacrificing this good landfill cover material to act as a foundation material for other dredged material.

General Comments

75. The following comments may be made with regard to dewatering dredged material for use as sanitary landfill cover.

- a. Dredging quantities and rates should be controlled to maintain thin lift placement in the dewatering disposal sites if the entire lift of dredged material is to be dewatered.
- b. Initial lift thickness affects the rate of dewatering. Thicker lifts have a somewhat slower rate of dewatering because continuing consolidation of underlying dredged material supplies additional water to the dredged material surface for an extended period of time.

- c. Good disposal site management practices should be followed to assure maximum dewatering of the dredged material. These practices should include:

 - (1) Thin lift placement.
 - (2) Compartmentalization of large disposal sites.
 - (3) Prompt removal of weir boards for removal of water ponded during the disposal operations.
 - (4) Continued periodic lowering of the weir crest elevation to allow prompt removal of precipitation. This continuing action is necessary as the dredged material surface subsides from consolidation and dewatering.
- d. Any estimated water content of the dried dredged material is of necessity an average value. In cohesive materials there will be a very distinct gradation of water content from top (drier) to bottom (wetter) of the dried crust. As the sediments become more coarse-grained, the average water content of the dried material will more closely reflect the conditions throughout the dried material.
- e. When thick lifts of dredged material must periodically be placed, this material may ultimately be dewatered to depths greater than those found in this study if it is possible to harvest the dried material at intervals before the next disposal operation.
- f. If requirements on landfill cover moisture contents are rigid, it might be advantageous to conduct field tests to determine the actual moisture content at completion of evaporative drying. If the water contents at completion of drying are not within specifications it might be necessary to provide for a minimal amount of rehandling of the dredged material, i.e. discing to aerate, etc. to bring the water content into acceptable limits.
- g. Since dried dredged material has not previously been used as sanitary landfill cover, it may be necessary to modify the procedure being utilized as the first such operation begins.

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APPENDIX A: SCHEMATIC DRAWINGS OF DEWATERING DISPOSAL SITES

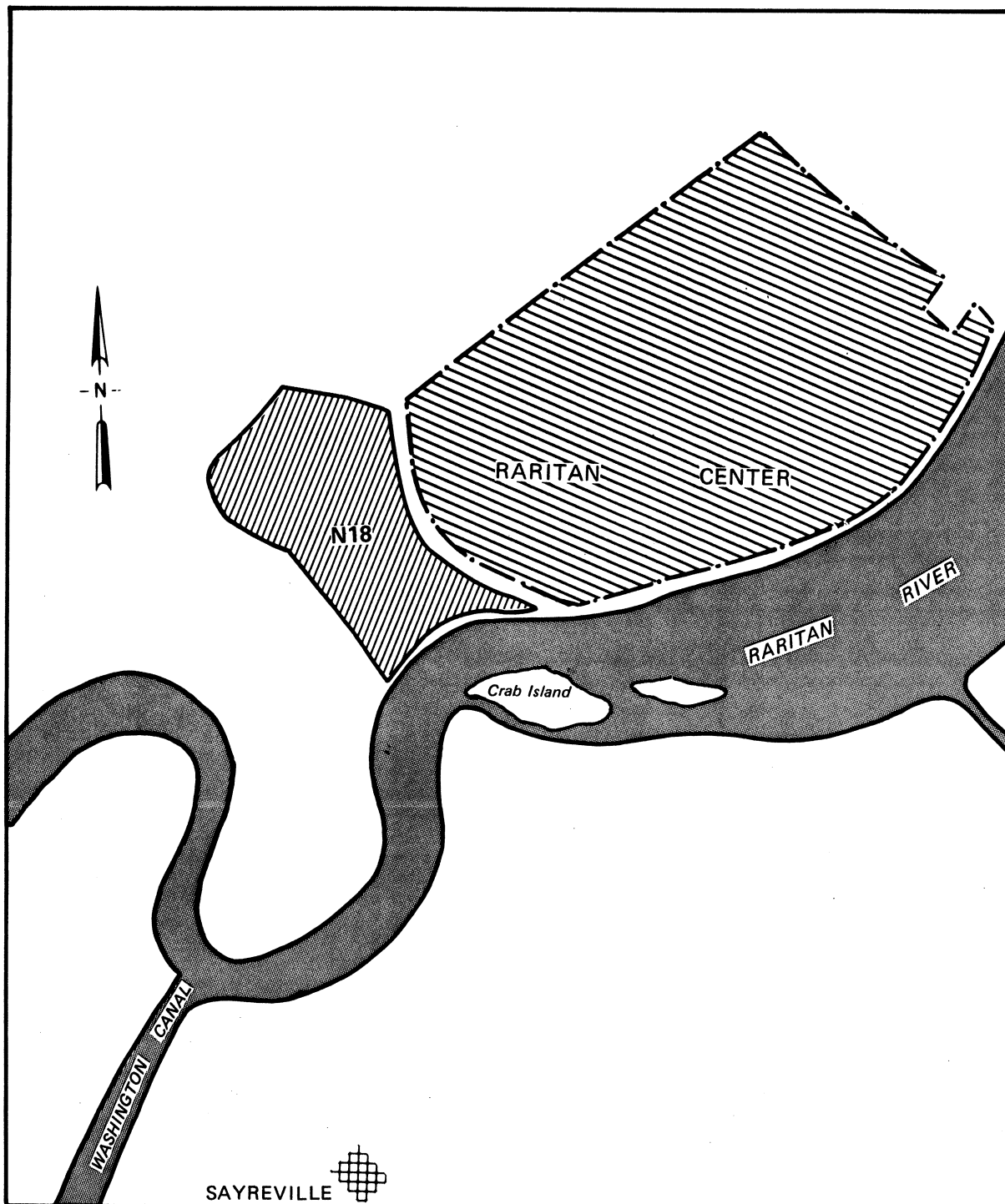


Figure A1. Schematic drawings of disposal sites N18 and Raritan Center

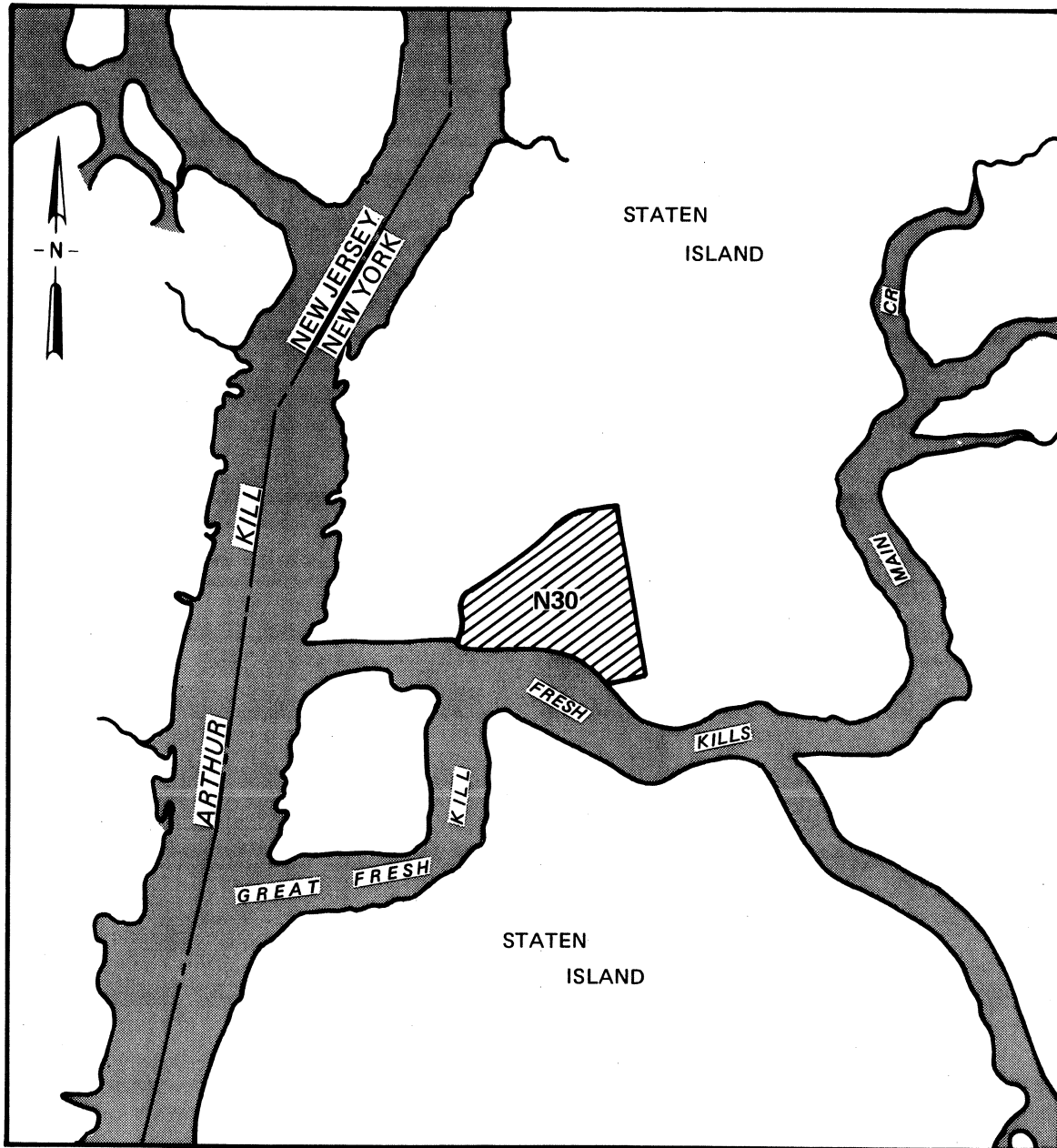


Figure A2. Schematic drawing of disposal site N30

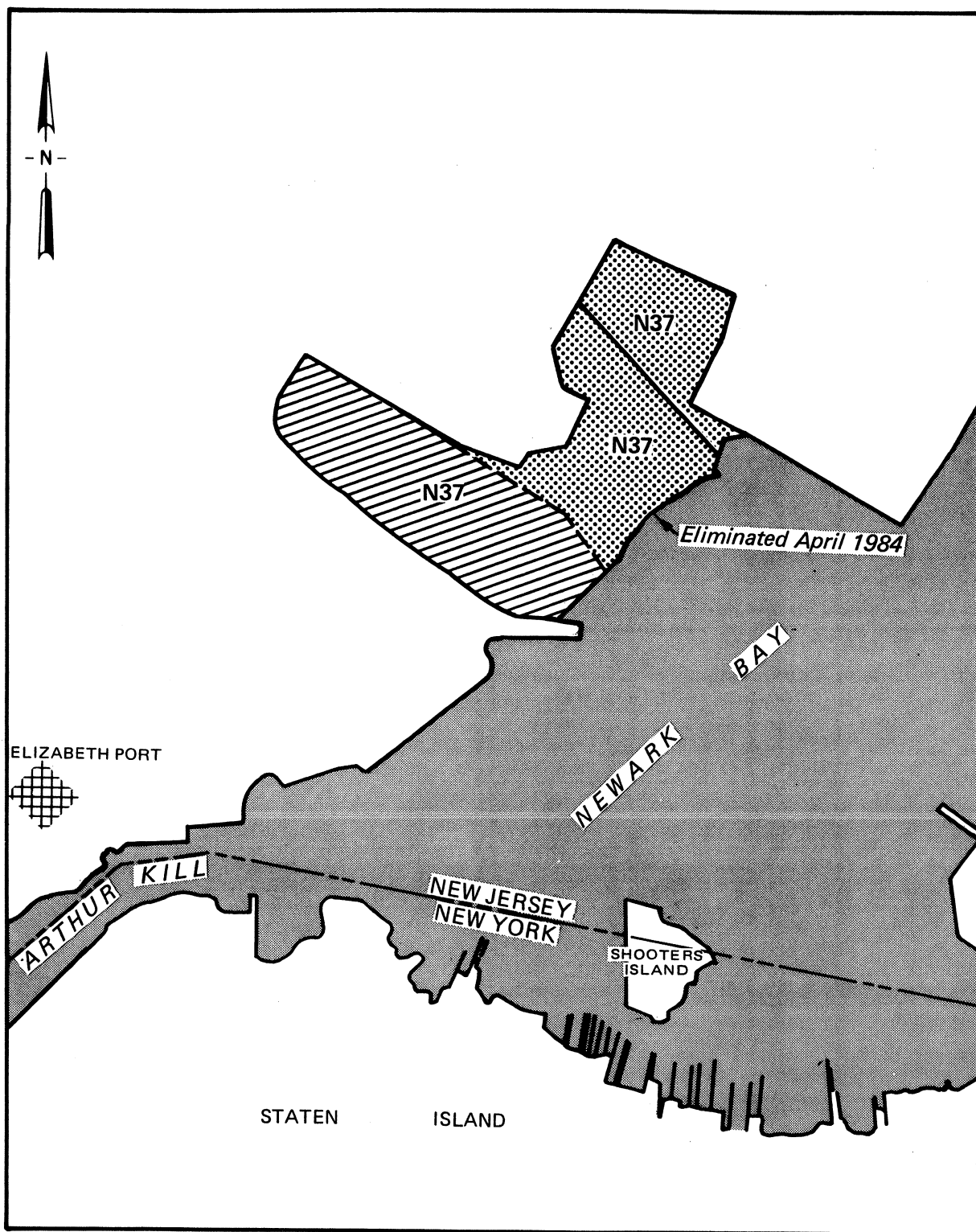


Figure A3. Schematic drawing of disposal site N37

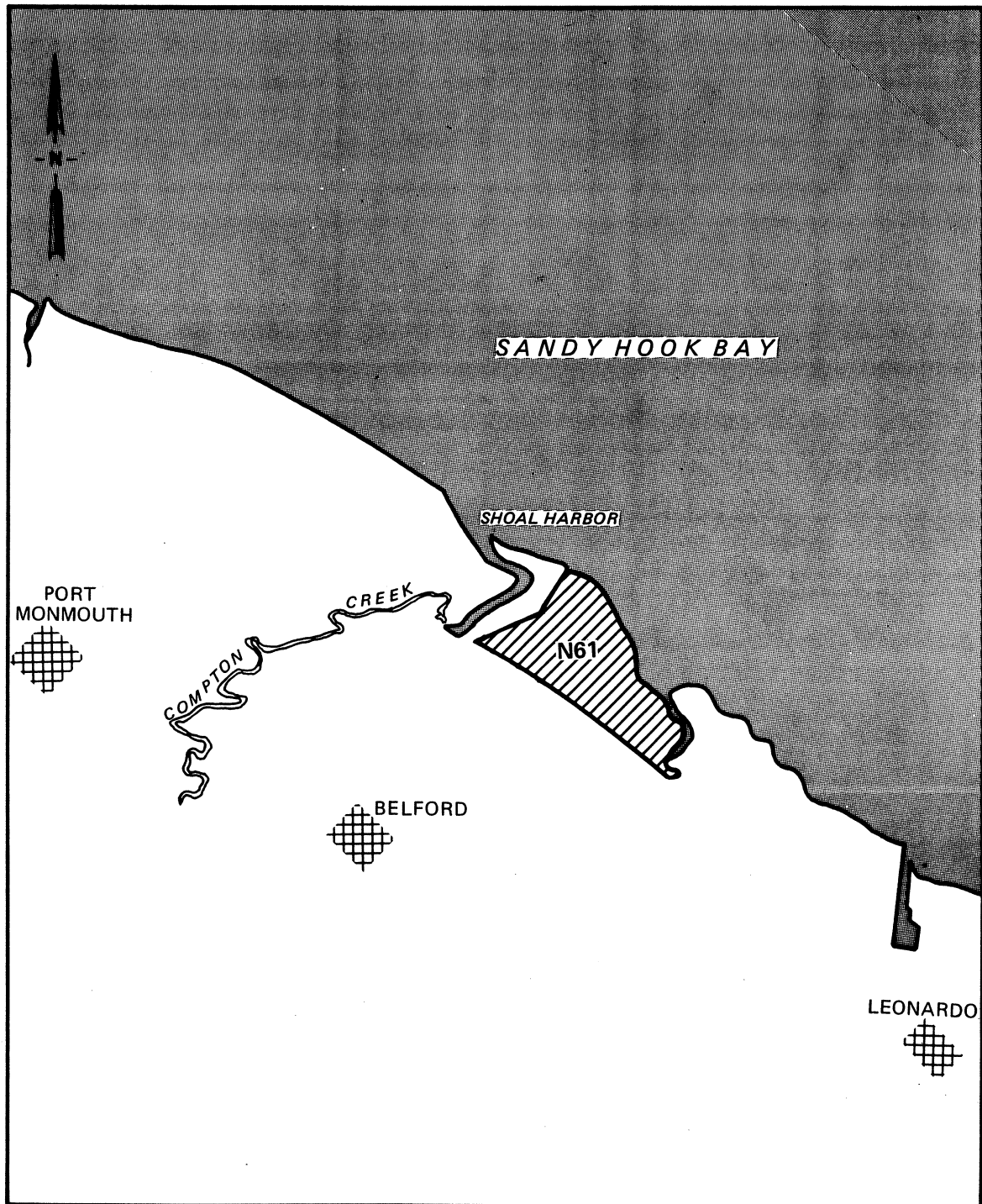


Figure A4. Schematic drawing of disposal site N61

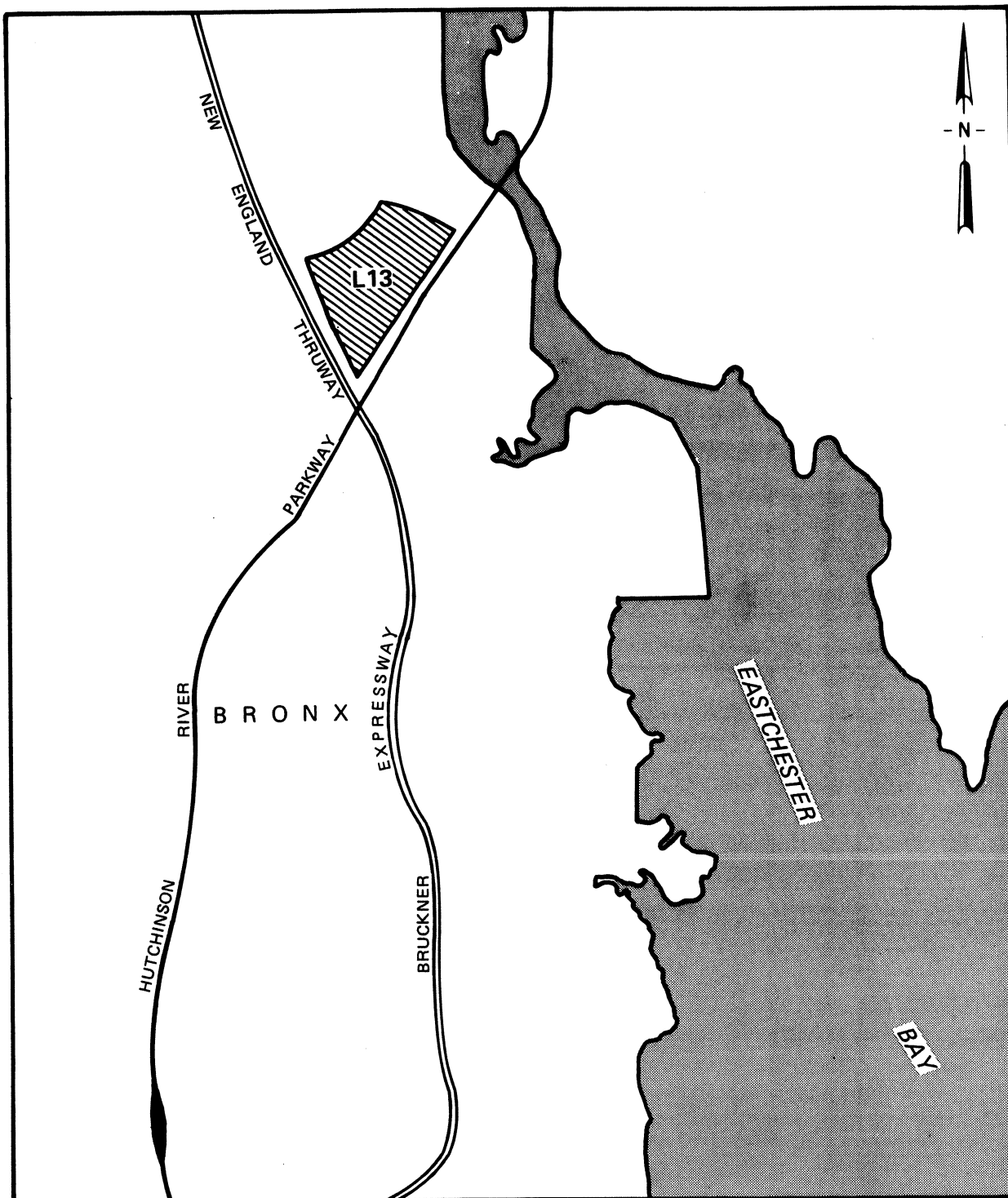


Figure A5. Schematic drawing of disposal site L13

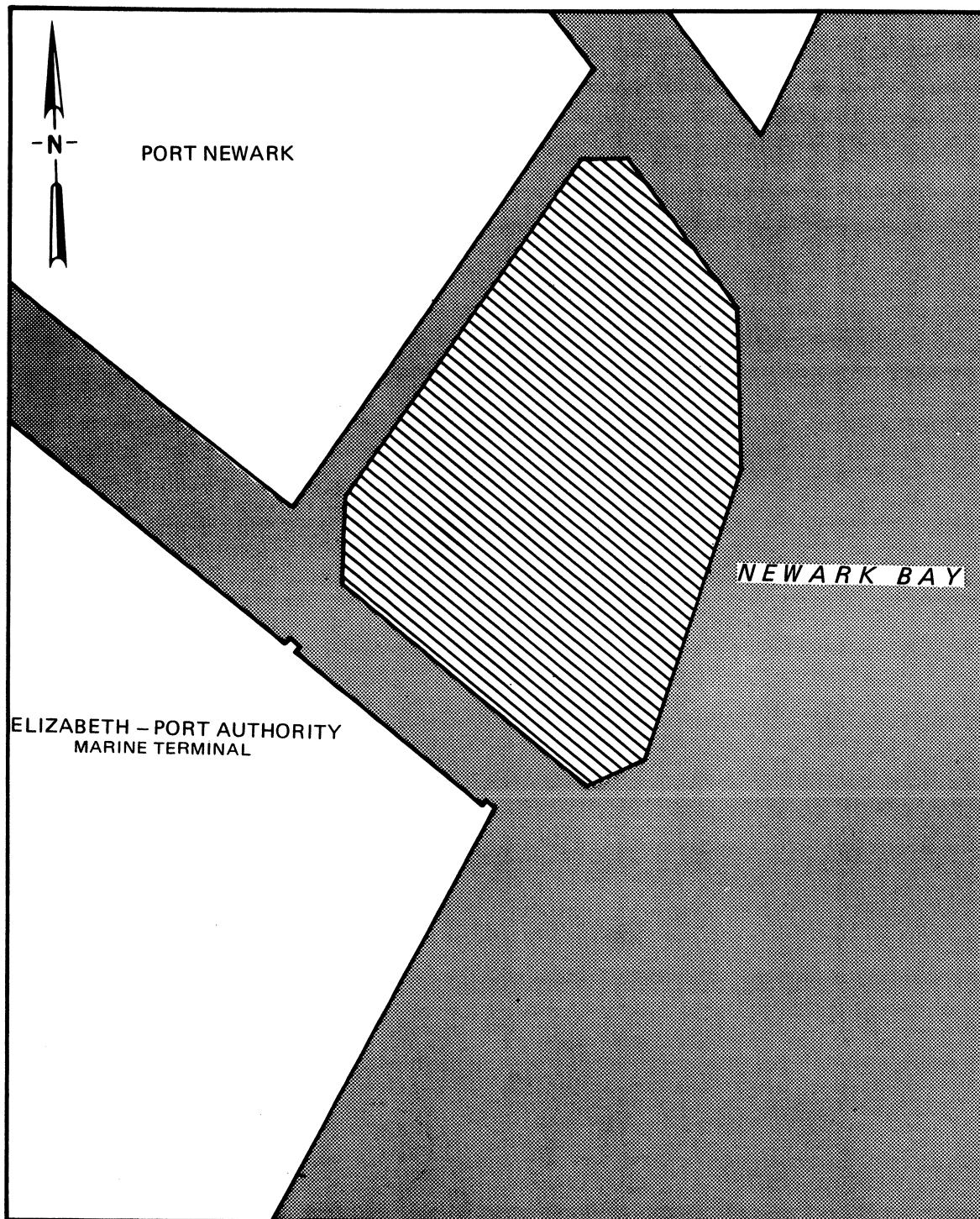
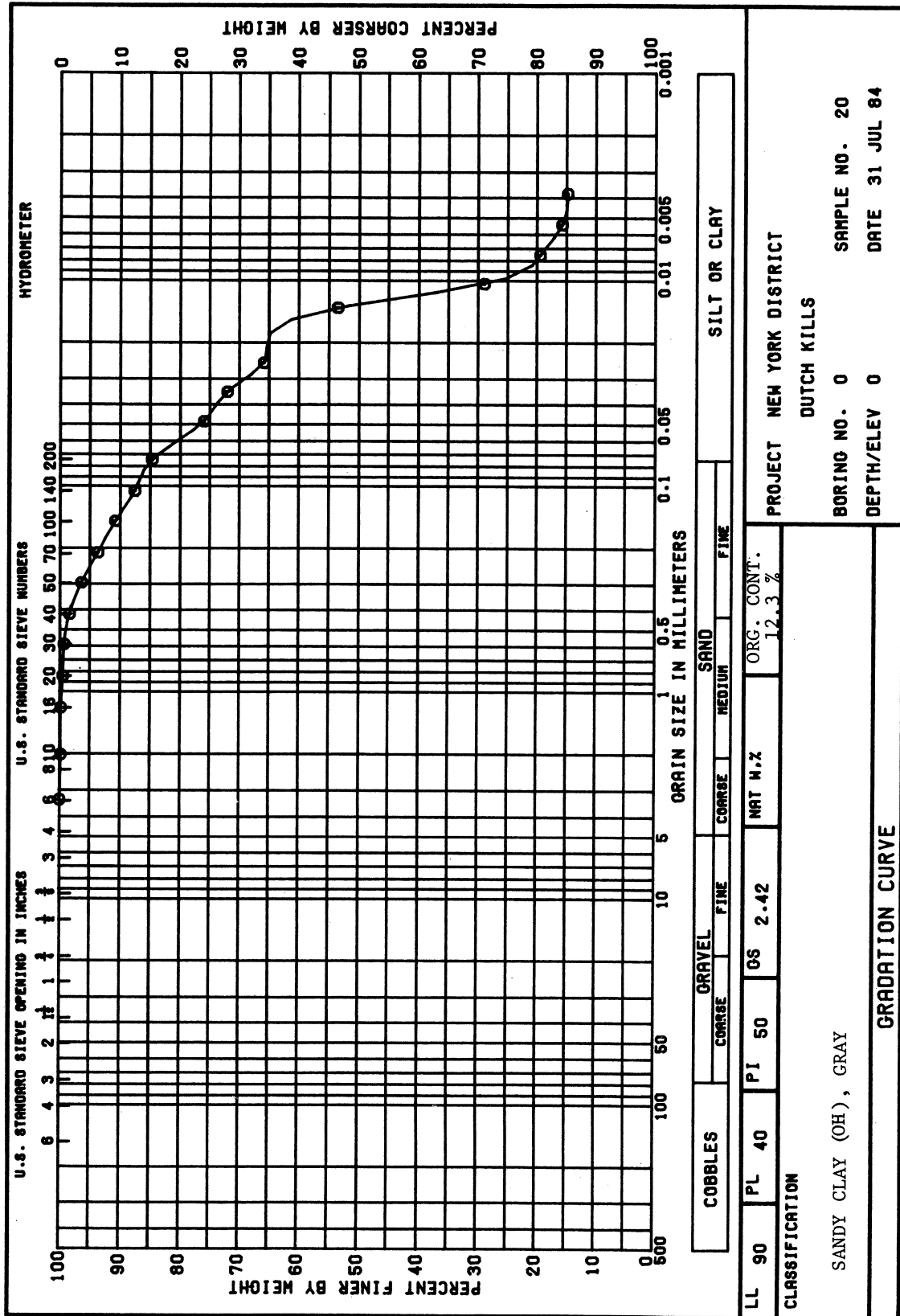
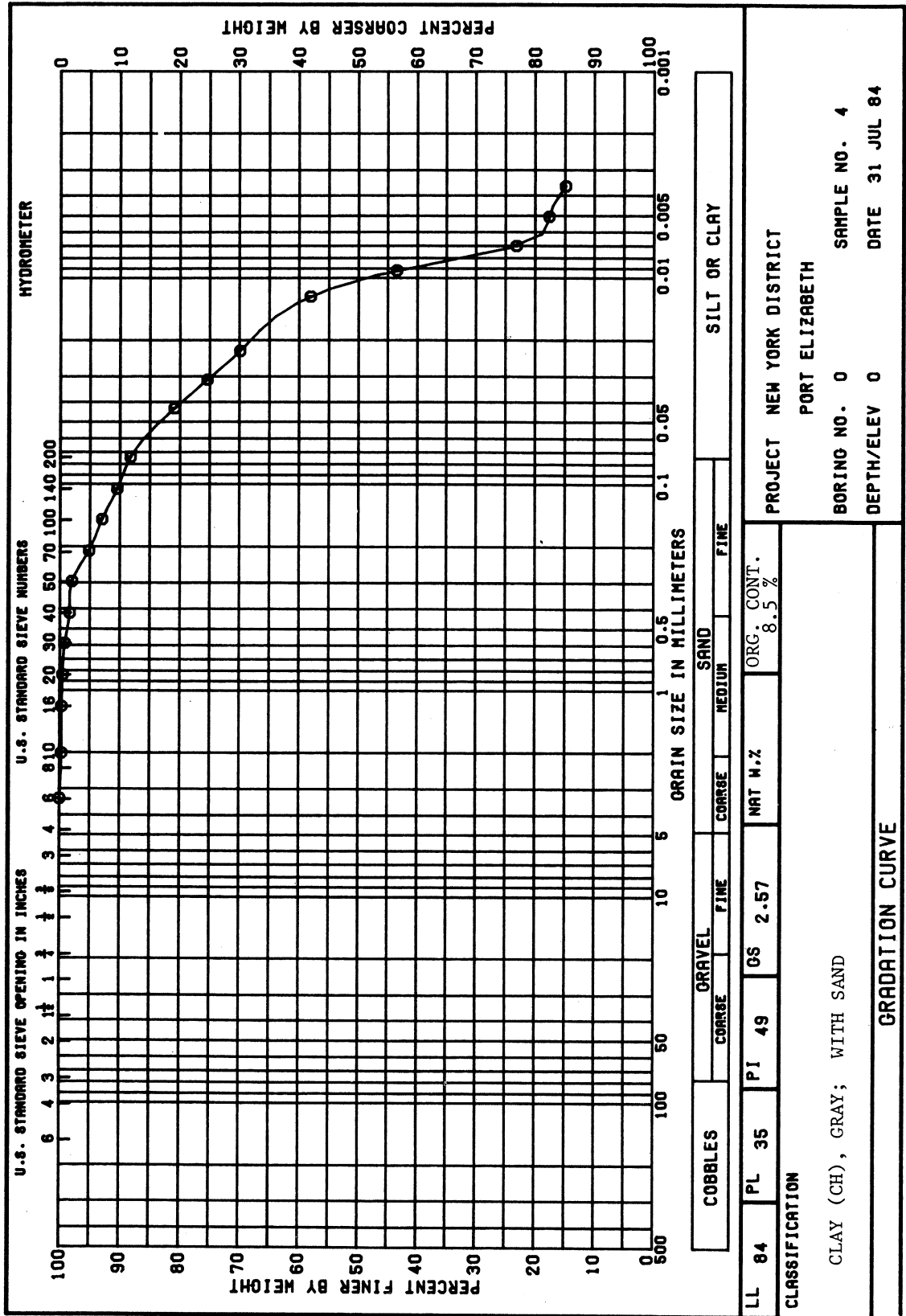


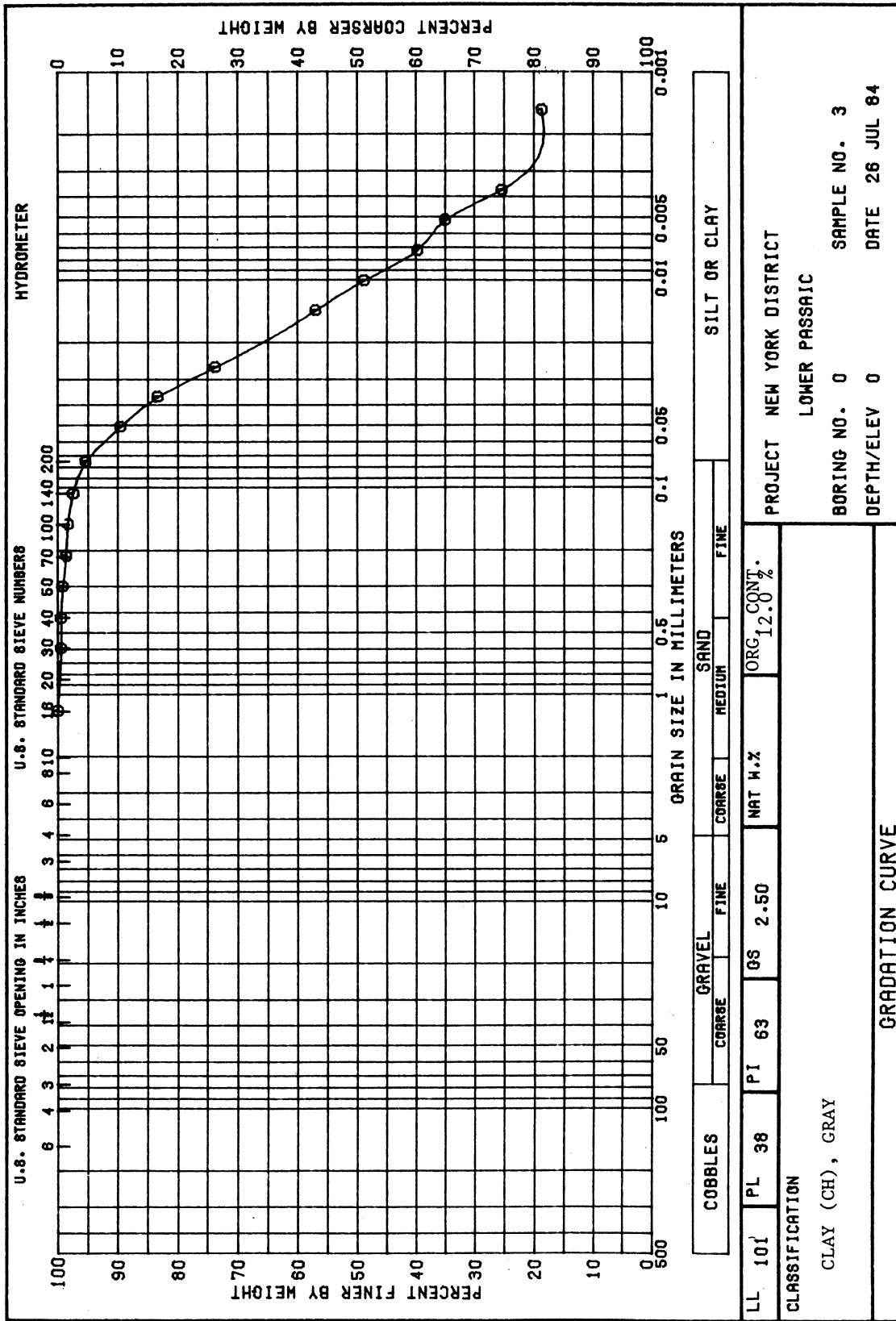
Figure A6. Schematic drawing of Newark Bay disposal site

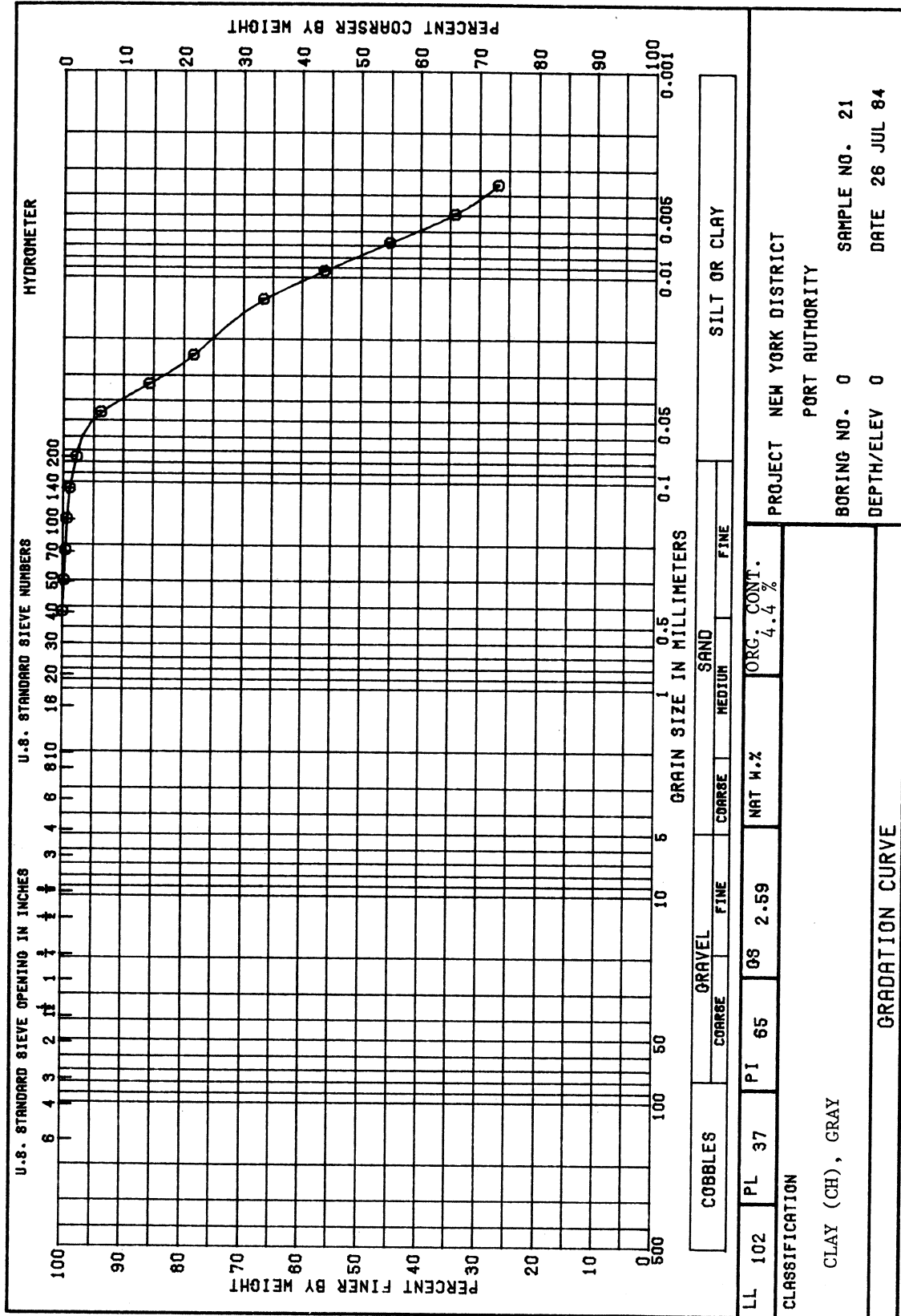
APPENDIX B: GRAIN-SIZE DISTRIBUTION CURVES

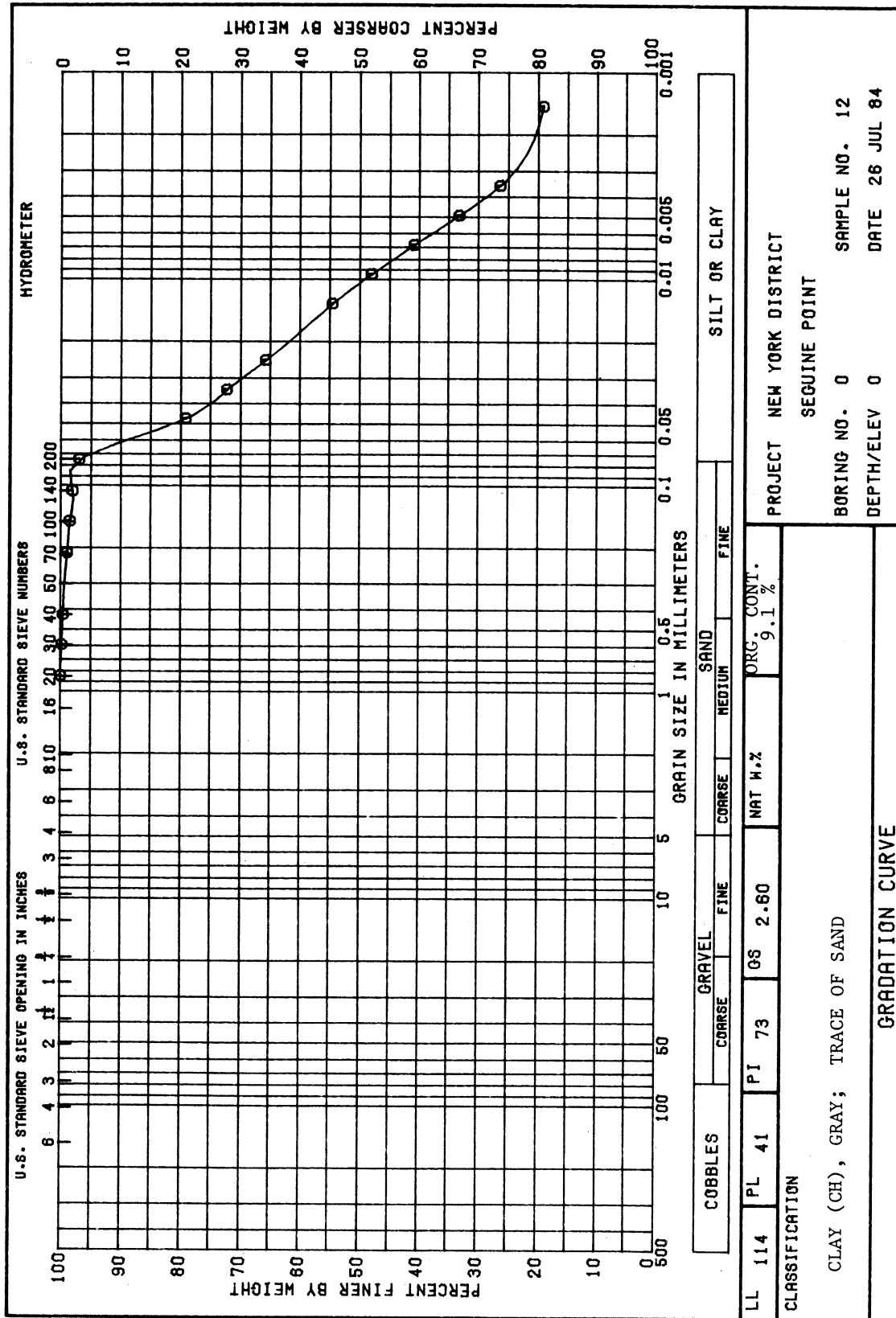


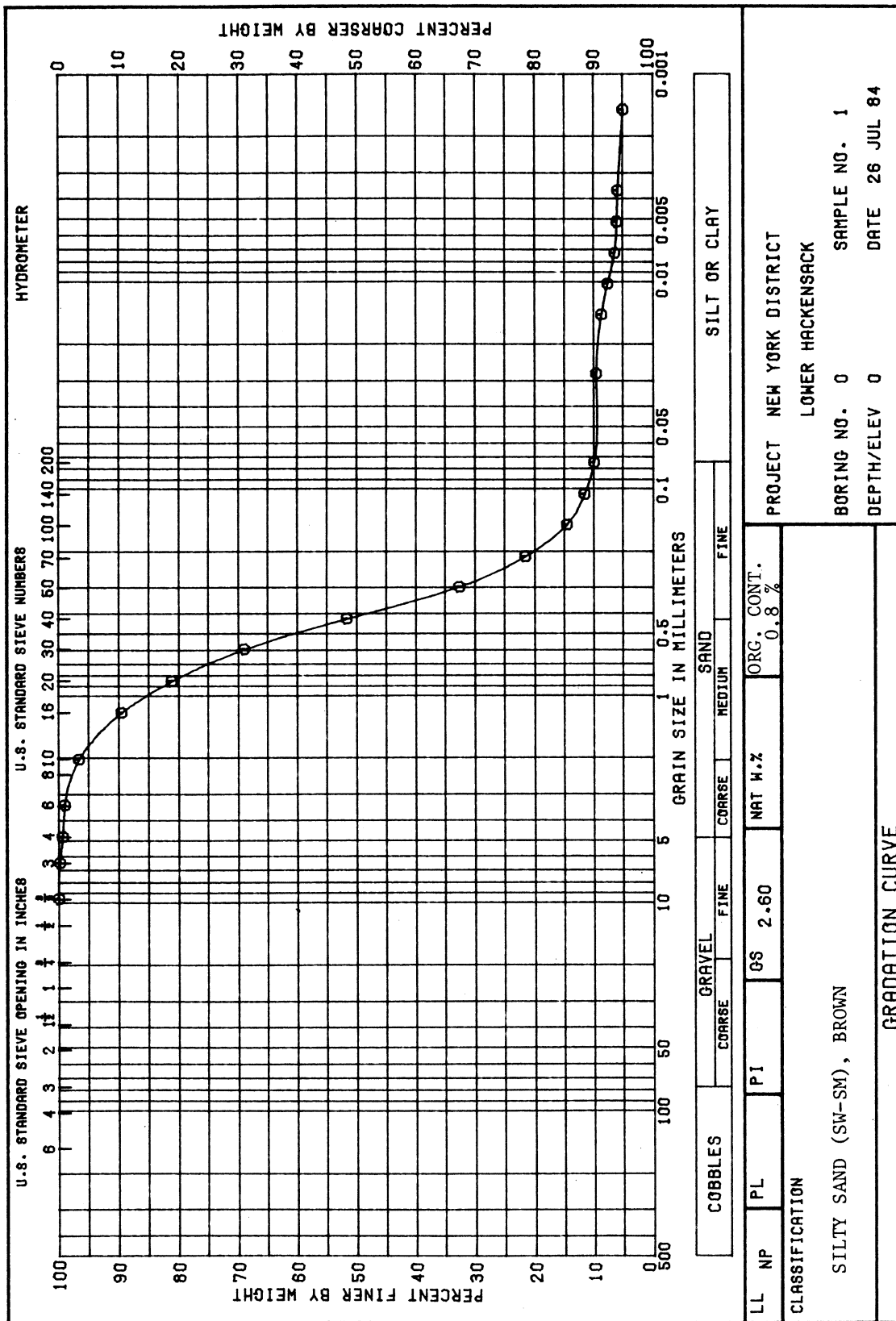


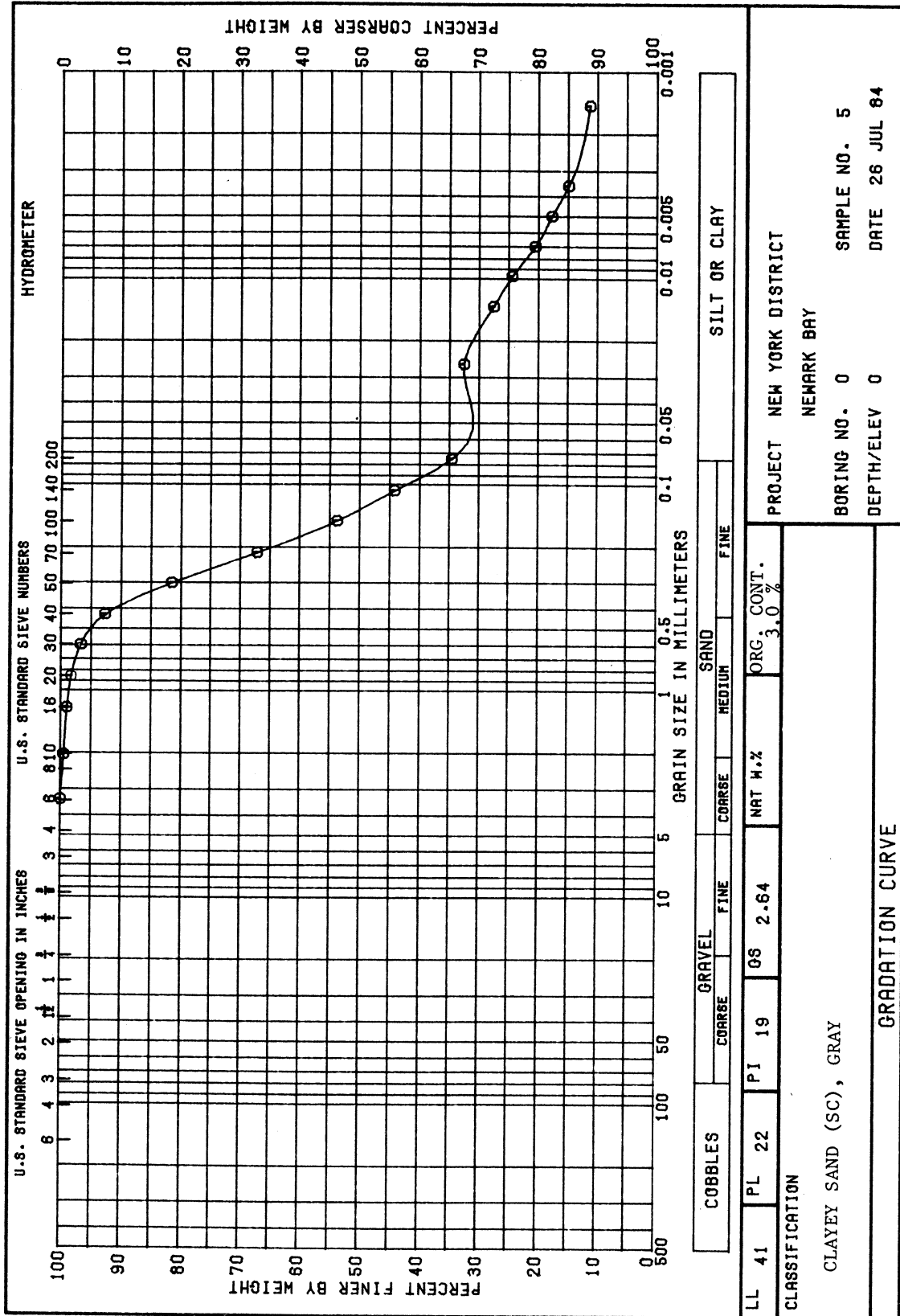
PROJECT NEW YORK DISTRICT		BORING NO. 0		SAMPLE NO. 4	
PORT ELIZABETH		DEPTH/ELEV 0		DATE 31 JUL 84	
LL 84		PL 35		PI 49	
OS 2.57		NAT W.2		ORG. CONT. 8.5 %	











PROJECT NEW YORK DISTRICT

NEWARK BAY

BORING NO. 0 SAMPLE NO. 5

DEPTH/ELEV 0 DATE 26 JUL 84

